# NAVAL POSTGRADUATE SCHOOL
## Monterey, California


# THESIS

**A DECISION-MAKING MODEL UTILIZING INFORMATION TECHNOLOGY: COMBINING THE FEATURES OF THE INTERNET, PUBLIC PARTICIPATION AND PROVEN DECISION-MAKING METHODS**

by

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December 1999

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# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | December 1999 | Master's Thesis |

**4. TITLE AND SUBTITLE :**
A DECISION-MAKING MODEL UTILIZING INFORMATION TECHNOLOGY: COMBINING THE FEATURES OF THE INTERNET, PUBLIC PARTICIPATION AND PROVEN DECISION-MAKING METHODS

**5. FUNDING NUMBERS**

**6. AUTHORS**
Timika L. Burnett and Mehmet Ergun

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Naval Postgraduate School
Monterey, CA 93943-5000

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** ***(maximum 200 words)***

This thesis research combines several proven methods by which public participation can be used more effectively in a government decision-making process. The research involved fulfills three primary purposes. First, the research provides a flexible user-friendly internet-based platform, whereby the knowledge level of a disparate group of stakeholders can be improved with respect to a complex technical subject. Second, the research demonstrates a method by which stakeholder consensus is derived. Third, the research exhibits a method by which public values are aggregated, whatever the level of consensus; the data is then provided to the government for use in a decision-making model.

**14. SUBJECT TERMS**
Web Technology, Internet, Information Technology, Public Participation, Decision-Making, Value Tree Analysis, Mutli-Attribute Utility Theory, Analytical Hierarchy Process, Delphi Method, Median Ranking Method, Hungarian Method, Rank Correlation and Aggregation.

**15. NUMBER OF PAGES**
101

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 19. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT**

from the

**NAVAL POSTGRADUATE SCHOOL**
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# ABSTRACT

This thesis research combines several proven methods by which public participation can be used more effectively in a government decision-making process. The research involved fulfills three primary purposes. First, the research provides a flexible user-friendly internet-based platform, whereby the knowledge level of a disparate group of stakeholders can be improved with respect to a complex technical subject. Second, the research demonstrates a method by which stakeholder consensus is derived. Third, the research exhibits a method by which public values are aggregated, whatever the level of consensus; the data is then provided to the government for use in a decision-making model.

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# I. INTRODUCTION

## A. BACKGROUND

Since the end of the Cold War, the United States has experienced a significant reduction of military forces and bases. The Base Realignment and Closure (BRAC) commission was established in 1993 for a single purpose: "to quickly dispose of excess activities, as designated for closure or realignment by the U.S. Congress, to local communities for reuse and economic revitalization." (NAVFAC, 1999) The base closures not only burden the local government and its people with decreased revenue and increased unemployment; but, the closures leave contaminants behind, where the polluted lands and waters increase the risk of public health and safety. In 1984, Congress established the Defense Environmental Restoration Program (DERP) to evaluate and remedy contamination from past Department of Defense (DOD) activities, and to protect human health and environment from risks associated with contamination of DOD lands. DERP was originally funded by DOD Environmental Account (DERA), whose purpose is to provide funding for cleaning at operational installations and formerly used defense sites. As a result of BRAC decisions, the number of restoration sites has grown dramatically, having doubled since 1989 to approximately 4500 sites today. More specifically, the current number of U.S. Navy activities slated for closure is 178 and the property at 91 of these activities has been or is slated for disposal. (NAVFAC, 1999) The administrative burden for the overwhelming number of closure and cleanup projects has grown correspondingly. DOD responded to this growth by devolving DERA into separate Army, Navy, and Air Force restoration programs. The DOD now serves as a

coordinator for the services, and each service is given the responsibility of managing its program more effectively. Breaking the organization into components also allows each office to be more responsive to stakeholders of any given project.

The naval component, known as the Department of the Navy's Environmental Restoration Program (ERP, N) is the responsibility of the Office of the Assistant Secretary of the Navy for Installations and Environment (ASN (I&E)). Through the office of the Chief of Naval Operations (CNO), the Naval Facilities Engineering Command (NAVFAC) manages all shoreside environmental projects and programs, providing technical expertise to support the Navy's environmental initiatives and coordinates with legislative and regulatory agencies. NAVFAC also manages a natural resource program to enhance the environmental attributes of its land, forests and wildlife. (NAVFAC, 1999) Ten engineering field divisions and engineering field activities, located across the United States and Europe, provide engineering support and services to the naval shore establishment. The Engineering Field Activity, West (EFA, West) serves as the NAVFAC regional headquarters for Central and Northern California, as well as Nevada.

EFA, West officials face the challenge of choosing remediation technologies that satisfy several goals such as reducing cost and decreasing human and ecological risk, while satisfying the public. The problem EFA, West faces is to choose the best treatment technology using public input. However, EFA, West is not certain as to how to operationalize public values. Including public opinion into a decision-making process has been a difficult task for government officials because of several barriers that exist for

utilizing public input such as: geographic distance, logistics cost, available time, and a structured model for aggregating input.

## B. PURPOSE

This thesis research is one of a few which combines several proven methods by which public participation can be used more effectively in a government decision-making process. The research involved fulfills three primary purposes. First, the research provides a flexible user-friendly internet-based platform, whereby the knowledge level of a disparate group of stakeholders can be improved with respect to a complex technical subject. Second, the research demonstrates a method by which stakeholder consensus is derived. Third, the research exhibits a method by which public values are aggregated, whatever the level of consensus; the data is then provided to the government for use in a decision-making model.

The method used in this thesis research may be useful to any organization which must satisfy a heterogeneous collection of stakeholders with different values and interests. The methodology addresses the commonplace problem of having to aggregate the public's values after deriving as much consensus as possible among the participating members. The method may help any organization interested in utilizing the concerns of stakeholders as an integral part of the decision-making process.

## C. METHODOLOGY

The methodology used in this thesis research consists of the following:

- Conduct a literature review of research on various decision-making and statistical methods including Multiattribute Utility Theory (MAUT), Value Tree Analysis (VTA), Analytical Hierarchy Process (AHP), Delphi method, and various aggregation methods.

- Research characteristics of Restoration Advisory Boards (RABs) from the following sites: Naval Air Station (NAS) Alameda, Concord Naval Weapons Station, Mare Island Naval Shipyard, NAS Moffet Field, Treasure Island Naval Station, Treasure Island Naval Station-Hunters Point Annex, Oakland Fleet and Industrial Supply Center (FISC). Utilize the characteristics to assign the roles to proxy-RAB members.[1]

- Develop a discussion forum for the discussion phase of the Delphi method, where stakeholders can voice their opinions and educate others on the consequences of various remedy-technology alternatives. Readily available and free commercial software is used to develop the forum.

- Ask the proxy-RAB panel to use the forum to express their site-specific concerns (i. e. values) regarding remedy technologies. In each of two Delphi rounds, the panel is asked to rank the set of values in order of importance. The level of association between the two rounds is determined through the used of simple aggregation methods and correlation determination.[2].

- Publish the results of the rankings on the web after each round of Delphi for further discussion and ranking.

- Determine the proxy-RAB members' representative final ordinal ranking of the set of alternatives using an aggregation technique.

- Convert final ordinal ranking into attribute weights.

- Construct the completed value tree.

## D. JUSTIFICATION FOR THE STUDY

This thesis research involves the integration of proven decision-making methods, namely the Delphi method and VTA using MAUT, into an internet-based platform. Traditionally, the Delphi method is performed by sending questionnaires to stakeholders (RABs), or organizing a conference at a specific location. This thesis research uses an

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[1] Due to time constraints of research, volunteers, none of them belong to RABs, study the characteristics of RABs and subsequently role play for genuine RAB members.

[2] Originally, the Median Ranking method and the Hungarian method were used measure the degree of divergence (or convergence) of the proxy-RAB members' concerns (i.e. values) at the end of each round. Efforts to derive an assignment matrix failed due to the data size; and as a result, simpler methods of aggregation and correlation were used to legitimate the consensus derived in developing the value tree.

internet-based platform to eliminate the logistic barriers such as costs involved with administration and logistics and time for all stakeholders to gather. The mean value, standard deviation and correlation coefficients are calculated to determine the level of association between stakeholders' opinions, and final consensus.

## E. RESEARCH QUESTIONS

*The primary research question in this thesis research is:*

What is a pragmatic and theoretically sound method to gather the public's opinion into a rigorous decision-making process by using information technology?

*The secondary research questions are:*

- Could this methodology be useful in explaining the many considerations in government decisions?
- Can the Delphi be implemented on the Internet?
- How can a technology choice problem be structured by using decision-making methods such as Delphi, MAUT, VTA or AHP?

## F. RESEARCH SCOPE AND LIMITATIONS

The scope of this thesis is to develop a web-based communications structure for stakeholders to voice their opinions anonymously, and rank their preferences according to their specific values after using the communication structure to learn more about a complex and technical subject. Moreover, this research combines the various decision-making methods to reach a group's decision output, which will be given to EFA, West officials to decide to adopt the methodology used in this research.

Although the research provides a valuable demonstration of combining decision-making techniques with the Internet, the research has some limitations. First, proxy-RAB members substituted for real RAB members due to time constraints. It is impossible to

know for certain whether the research results would be different using real RAB members. An important factor to consider is that proxy-RAB members do not have a genuine and long-held understanding of the concerns that are particular to the actual sites they are representing. Second, time constraint also limited the amount of time for discussion during Delphi rounds. Furthermore the number of Delphi rounds is limited to two, whereas normally three or more are recommended.

## G. OVERVIEW AND ORGANIZATION

This thesis is comprised of five chapters. This chapter provides background concerning EFA, West's involvement in the San Francisco Bay Sediment Project. The research describes the use of an electronic internet-based forum, where stakeholders can voice their opinions and prioritize their concerns vis-à-vis remedy technologies.

Chapter II is the review of the literature, which explains various decision-making and statistical techniques including MAUT, VTA, AHP, the Delphi Technique, the Median Ranking Method, the Hungarian Method, and various aggregation methods. Chapter III discusses the formulation and implementation of an internet-based discussion forum that allows geographically distant proxy-RABs to list their important concerns, and rank the set of attributes anonymously. Chapter IV provides the research results, and evaluates the efficiency of the internet, and provides recommendations for developing new methodologies to accomplish the purpose of this thesis.

## H. SUMMARY

For decades, the government has encouraged public participation; however, organizations do not have effective models to incorporate public opinion. The Delphi method allows the public to participate in a decision-making process, where the public

voices its concerns and ranks its attributes anonymously. Delphi has proven itself as a systematic and effective way of involving public values. This research investigates whether Delphi can be combined with VTA and MAUT using Internet-based elicitation techniques. This research creates a bridge that allows government agencies to use such methodology in future decision-making practices.

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# II. LITERATURE REVIEW

## A. INTRODUCTION

This chapter reviews various types of evaluation and decision-making methods. The purpose is to furnish readers with a background of selected decision-making methods, which will provide the necessary tools to utilize stakeholder's values in the decision-making process. This chapter is divided into three sections: 1) Multi-criteria decision making techniques, 2) Value solicitation and consensus building methods, and 3) Aggregation methods. Multi-criteria decision-making techniques, specifically Value Tree Analysis (VTA) utilizing Multi-attribute Utility Theory (MAUT), and a competing method, Analytic Hierarchy Process (AHP) are investigated, where simply stated procedures and applications are provided. Value solicitation and consensus building focus on the basics of the Delphi method, the consensus building technique used in this thesis. An application of the Delphi using information technology is demonstrated in Chapter III. The third section lists various types of aggregation techniques, and explains the importance of aggregation when there are various sizes of groups of experts that need to make a group decision.

## B. BACKGROUND - ASPECTS OF DECISION-MAKING

Figure 1 illustrates two major aspects involved in the decision-making process. The first is Procedural and Technological Interventions, where well-developed models and guidelines are introduced to help facilitate the decision-making process. The second aspect encompasses the major features of decision-making, which explains how a problem evolves and the need for understanding the problem before making a decision.

While the authors give no formal title, this thesis will reference this aspect as Problem Structuring and Legitimation.

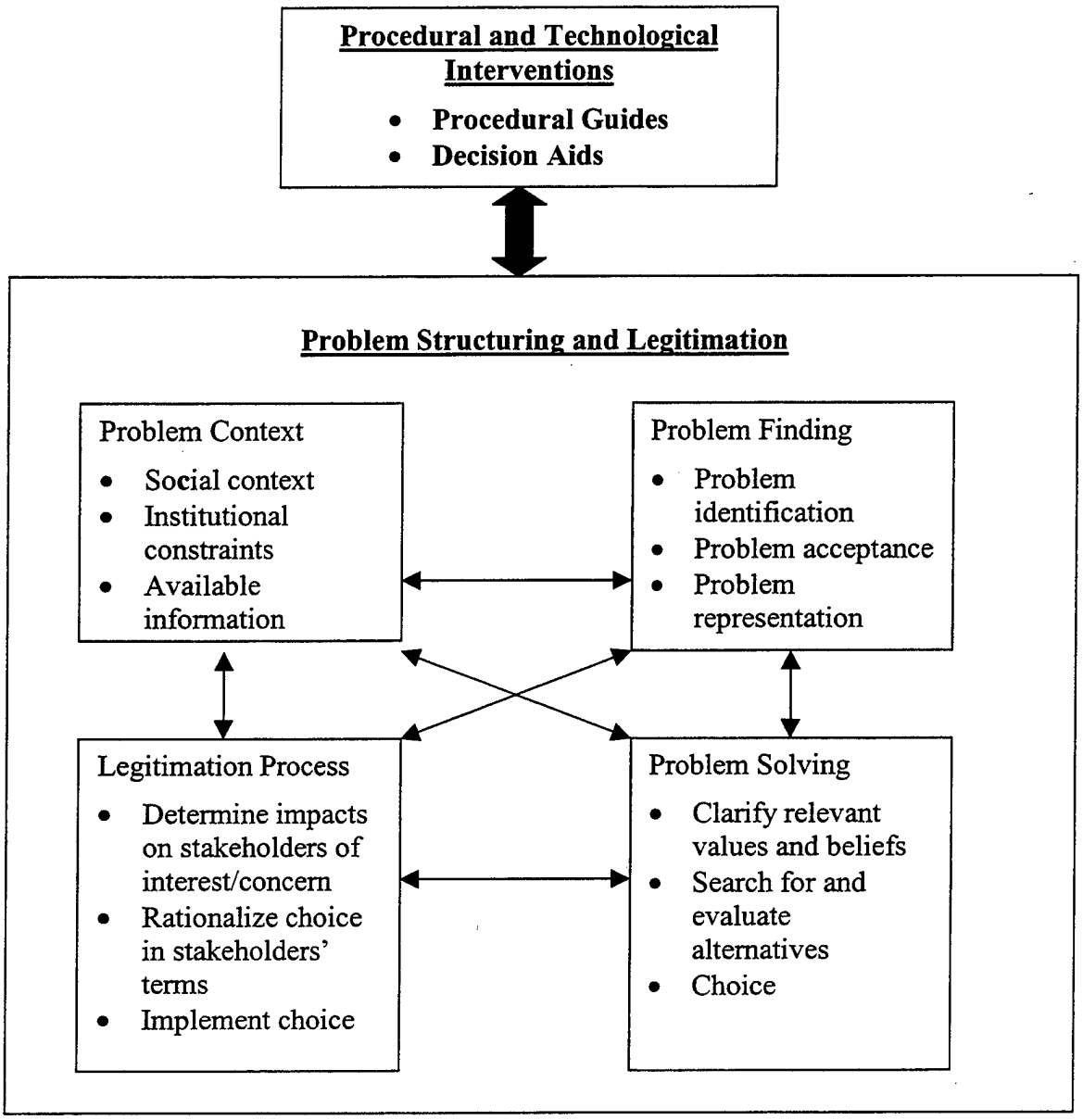


Figure 2.1. Aspects of decision-making (Kleindorfer, Kunreuther and Schoemaker, 1993). Note: Changes have been made to original to reflect the relation between the two aspects (Procedural and Technological Interventions and Problem Structuring and Legitimation).

The two aspects explained above are a product of prescriptive and descriptive theories based on research by Kleindorfer, Kunreuther and Schoemaker (1993). While both theories address the "how" of a decision, descriptive analysis examines the human quest for making decisions, while the prescriptive aspect defines measures upon which a decision should be based. Consider a group decision situation. An illustration of descriptive theory in group decisions would be sociology, which "provides a perspective on the nature of information diffusion processes and the role of social norms in the decision-making process." (Kleindorfer, Kunreuther and Schoemaker, 1993, p. 5) Game Theory, a prescriptive example, focuses on competition, and is defined as "the study of how optimal strategies are formulated in conflict." (Brown, 1998, p. 31) The following paragraphs explain the need for both aspects, and the interdependence that must exist for a sound decision-making process.

### 1. Procedural and Technological Interventions

Procedural and Technological Interventions provide structured guidelines for individuals or groups who must make a decision. In operations analysis, models are developed to answer the well-known economic tradeoff problem of maximizing profit while reducing risk. Technology plays a significant role by introducing systems that help decision-makers evaluate complex problems.

Guidelines and models offer prescriptive solutions to a decision-maker; but at the same time, lack the human intervention that must be considered. The need for conflict resolution among decision-makers with different goals and objectives helps define the organization's structure and decision-making process. This void of the human psyche warrants the need for the descriptive aspect of evaluating complex problems.

## 2. Problem Structuring and Legitimation

In Figure 1, Problem Structuring and Legitimation describe some features involved in descriptive theory and is broken into four major categories: Problem context, problem finding, problem solving and legitimation process. (Kleindorfer, Kunreuther and Schoemaker, 1993) Problem context defines the social, institutional and informational environment of the decision process. Understanding problem context means recognizing who might be affected, who has power (or final authority), what information is available to the decision-makers, and if possible, what values or beliefs they hold regarding the problem in question.

Problem finding addresses the fact that a problem has been identified by the activity, accepted by the decision-maker(s), and represented to give them a decision opportunity. Problem solving involves making a choice that resolves the presented problem. This choice is based on understanding the relevant values and identifying solution alternatives. The Legitimation process consists of determining how the stakeholders will be affected by the chosen solution alternative, and rationalizing the choice of the decision-maker in terms of stakeholder values and interests. (Kleindorfer, Kunreuther and Schoemaker, 1993)

The upward arrow between Procedural and Technological Interventions and Problem Structuring and Legitimation (see Figure 1) represents the need for a problem to be well defined and understood by the decision-makers before utilizing a decision-making process. Kleindorfer, Kunreuther and Schoemaker state that "sound prescription must begin with good description." (1993, p. 10) The arrow's downward direction indicates that the use of specific types of Procedural and Technological Interventions may

help the decision-maker better understand and define the problem. If the desired outcome is not obtained, it is because of ill-defined factors that affect the overall problem. The arrows connecting the categories in the second aspect indicate there are no set procedures of which category should be resolved first. Rather, it is a redundant or cyclical process, where one change in one category affects the other three categories. Only when the decision-maker understands all four categories in the aggregate can the problem be considered well defined, and only then can the proper tools be selected or designed to help the decision-maker make decisions.

## C. MULTI-CRITERIA DECISION MAKING TECHNIQUES

Questions like "Is this plan wise?" "Should I choose option A or option B?" "How well is this program doing?" have been asked about social programs for decades (Edwards and Newman, 1982). But the idea that one could answer such questions systematically and in a manner other than by simply making an intuitive judgment, is a product of decision science research since the 1950s and 1960s. Organizations strive to work more efficiently by choosing programs worthy of support over those that are not, and providing guidance for programs in existence. At the same time, organizations devote resources and attention to develop satisfying methods to improve efficiency in programs.

### 1. Multi-Attribute Utility Theory (MAUT)

#### *a. Definition of MAUT*

Multi-attribute Utility Theory (MAUT) is a tool used to structure a decision-maker's preferences. MAUT presents the approach to determine the priorities of the decision-maker, and is a tool in which organizations can organize and aggregate its

evaluative efforts. MAUT applies to situations with uncertainty and multiple, often conflicting objectives (Murphy, 1997). According to Edwards, Guttentag, and Snapper (1975), MAUT depends on a few key ideas:

- When possible, evaluations should be comparative.
- Programs normally serve multiple constituencies (those that have the power to vote/elect).
- Programs normally have multiple goals, not all equally important.
- Judgments are inevitably a part of any evaluation.
- Judgements of magnitude are best when made numerically.
- Evaluations typically are, or at least should be, relevant to decisions.

Evaluations of programs that serve multiple constituencies should normally be addressed to the interests of those constituencies. Different constituencies can be expected to have different interests. If programs have multiple goals, evaluations should assess how well the programs serve the constituencies and the programmatic goals; this implies multiple measures and comparisons. Edwards and Newman state that using "multiple measures of effectiveness (which may well be simple subjective judgments in numerical form) makes less appealing the notion of social programs as experiments." (1982, p. 8) However, implementation of such experiments become more difficult as the number of measures needed for a satisfactory evaluation increases. Experimental or hard data can be easily incorporated in a MAUT evaluation, provided such data are available.

Edwards and Newman (1982) suggest that combining subjectivity with evaluation with numerical judgements serve several useful purposes:

- First, the combination partly closes the gap between intuitive and judgmental evaluations, and makes coexistence of judgement and objective measurement within the same evaluation easy and natural.

- Second, accepting subjectivity into evaluation provides an opportunity to combine links of values. For instance, "evaluation researchers often distinguish between process evaluations and outcome evaluations." (Edwards and Newman, 1982, p. 9) Process and outcome are different, but if a program has goals of both kinds, its evaluation can and should assess its performance on both.

- Third, the use of subjective inputs can reduce the time required for an evaluation to be executed. In as little as a week of concentrated effort, a MAUT evaluation can be used from its original definition of the evaluation problem to the preparation of the evaluation report.

### *b. Purposes for Evaluations*

According to Edwards and Newman, MAUT is a "widely applicable method of organizing and presenting evaluative information. As such, it is compatible with any other evaluative activity designed to yield numbers as outputs." (1982, p. 11) The organizational requirement for evaluation is normally based on the supposition that decisions need to be made. Sometimes, the decisions involve programmatic continuation, modification or elimination. Other decisions might revolve around program design, management, or process improvement.

Major evaluations are often required as a basis for potential major programmatic changes – up to and including the most major of all changes: the birth or death of a program. Funding-level decisions are also programmatic choices; the same program at two substantially different funding levels results in qualitatively different programs.

The aforementioned decisions share two characteristics. The first is that all evaluations require comparison of something with something else. An important

implication of the comparative nature of virtually every evaluation is that some of the comparisons are inevitably between the program as it is and the program as it might be – that is, between the existing and the conceptual programs or programmatic methods. The second is that programs virtually always have multiple objectives; consequently, evaluations should assess as many objectives as possible. MAUT serves as a useful tool in these cases because, as mentioned before, MAUT is directed at analyzing problems with multiple goals serving multiple constituencies.

### *c. Steps in a MAUT Evaluation*

In many decision theory books, authors attempt to define the pertinent steps that are used to execute the MAUT evaluation. Some have stated five steps, others more. To define each step clearly, the process is broken into seven steps, as used by Edwards and Newman (1982):

- Step one: Identify the objects of evaluation and the function or functions that the evaluation is intended to perform. The functions of the evaluation will often control the choice of objects of evaluation.

- Step two: Identify the stakeholders. Stakeholders are defined as "people who have an interest or stake in the program or entity being evaluated, and who are important enough so that their interests should be considered." (Edwards and Newman, 1982, p. 17)

- Step three: Elicit the relevant value dimensions or attributes from stakeholder representatives, and organize the value dimensions or attributes into a hierarchical structure.

- Step four: Assess the relative importance of each of the values identified in step three for each stakeholder group. Such judgements can be expected to vary from one stakeholder group to another; methods of addressing such value conflicts are important.

- Step five: Ascertain how well each object of evaluation (i.e. alternative) meets the values implicit in each attribute. To understand the level of any alternative's success in meeting an attribute requires measurements or

subjective expert judgements, or both. These measures and judgements must be converted into a common, comparable scale, called utility.

- Step six: Aggregate utilities with measures of importance. This is done with the general equation:

$$U_j = \sum_{i=1}^{n} w_i u_{ij}$$

Where $U_j$ is the overall or composite utility for the $j^{th}$ decision alternative; $w_i$ is the normalized weight assigned to the $i^{th}$ attribute; and $u_{ij}$ is the utility of the $j^{th}$ option on the $i^{th}$ attribute. The symbol $\Sigma$ means to sum the weighted utilities over all the attributes from the first (1) to the last (n). The larger the numerical value of U, the better. Therefore, whatever decision alternative received the largest U should be considered best among the alternatives.

- Step seven: Perform sensitivity analyses. The question underlying any sensitivity analysis is whether a change in the analysis will lead to different conclusions, for example, using different weights in the utility measurement. While conclusions may have emerged from step six, the conclusions deserve credence as a basis for action only after their sensitivity is explored in this step.

### *d. The Relation Between Evaluation and Decision*

Researchers have been concerned with the relationship between evaluation and decision, especially the academic evaluation researchers, who wonder whether or not their evaluations are used appropriately. Some evaluators believe their responsibility is to provide the relevant facts; and someone else should make the decisions. As a rule, the evaluator is not the decision-maker, and cannot compel the decision-maker to agree with the result of the evaluation, or to base decisions on it.

Edwards and Newman (1982) explain three devices that make evaluations more likely to be used in decision-making. The first and most important, is to involve the decision-makers heavily in the evaluative process; especially when the decision-makers

are among the most important stakeholders. The second is to make the evaluation as directly relevant to the decision as possible, preferably by making sure that the options available to the decision-maker are the objects of evaluation. The third is to make the product of the evaluation useful – which primarily means making it understandable. In this research, the proxy-RAB members (representing stakeholders) identify the parameters on which evaluators should focus. Additionally, the decision-makers use the stakeholder-defined value structure to make decisions.

#### *e. Summary*

This research conforms to the recommendations of Edwards and Newman by ensuring that decision-makers are involved in the evaluation process; by making evaluation as directly relevant to the decision as possible; and by making the product of the evaluation understandable. The latter point is particularly important in a publicly funded program that depends upon constituent satisfaction. Satisfaction, in turn, can only be produced by legitimating the decisions. In this spirit, the method adheres to the requirements needed to use the simple additive utility as depicted in Section C.1(c). The requirements for using the Additive Utility Function, and a further description of this method, are included in Appendix A.

### 2. Value Tree Analysis (VTA)

Complex evaluation problems can be structured by building a value tree (Edwards, 1980). Value trees are pyramid-like structures. At the top of the tree is generally one overall value. "Values are abstractions that help organize and guide preferences. They are most often expressed as statements of desired states, positive intentions, or preferred directions. The actions or objects of value may be such diverse

choices as social policies, marketing strategies, or individual consumer choices." (Winterfeldt and Edwards, 1986, p. 38) Values are also defined as a collection of objectives. Clemen states, "An individual's objectives taken together make up his or her values. They define what is important to that person in making a decision. A person's values are the reason for making decisions in the first place. Without objectives, it would not be possible to tell which alternative would be the best choice." (1996, p. 20)

Below the overall goal are several intermediate level goals, or objectives, needed to reach the overall goal. Intermediate goals can include fundamental and means objectives. Distinguishing between fundamental and the means objectives allows the decision-maker to structure the value tree. "Fundamental objectives reflect what we really want to accomplish and means objectives help achieve other objectives. Structuring the fundamental objective hierarchy is crucial for developing a multiple objective decision model." (Clemen, 1995 p. 44)

At the lowest level are the attributes, "which serve to explicate and operationalize higher level values and concerns." (Stillwell, Winterfeldt, and John, 1981 p. 1) An attribute is defined as the criteria for measuring the objectives. Rowe (1992) explains an attribute as the quantity measured on an attribute scale. An example of an attribute scale is the dollar amount if the objective is to minimize cost. Figure 2 is a simple example of a value tree.

According to Winderfeldt and Edwards, the theory of the use of value trees for evaluating options is straightforward: "the analyst simply uses the operational attributes, obtains estimates of how the options perform on these attributes, converts these estimates to utilities, weights the attributes, and carries out the appropriate calculations to generate

an overall evaluation of the options." (Winderfeldt and Edwards, 1986, p. 45) However, in practice this approach has difficulties:

- There may be too many attributes to carry out an evaluation.
- Some branches of the value tree (see Figure 2) may be irrelevant because some of the attributes might not have effect on the solution alternatives.
- The decision-maker may find higher level branches of the tree to be more meaningful than the attributes itself. The task of structuring relevant and meaningful operational attributes can be difficult.

Despite the difficulties mentioned above, a value tree is a useful tool. Winderfeldt and Edwards suggest that, "value trees are most often used as background material in the development of attribute sets for a formal evaluation." (Winderfeldt and Edwards, 1986, p. 45)

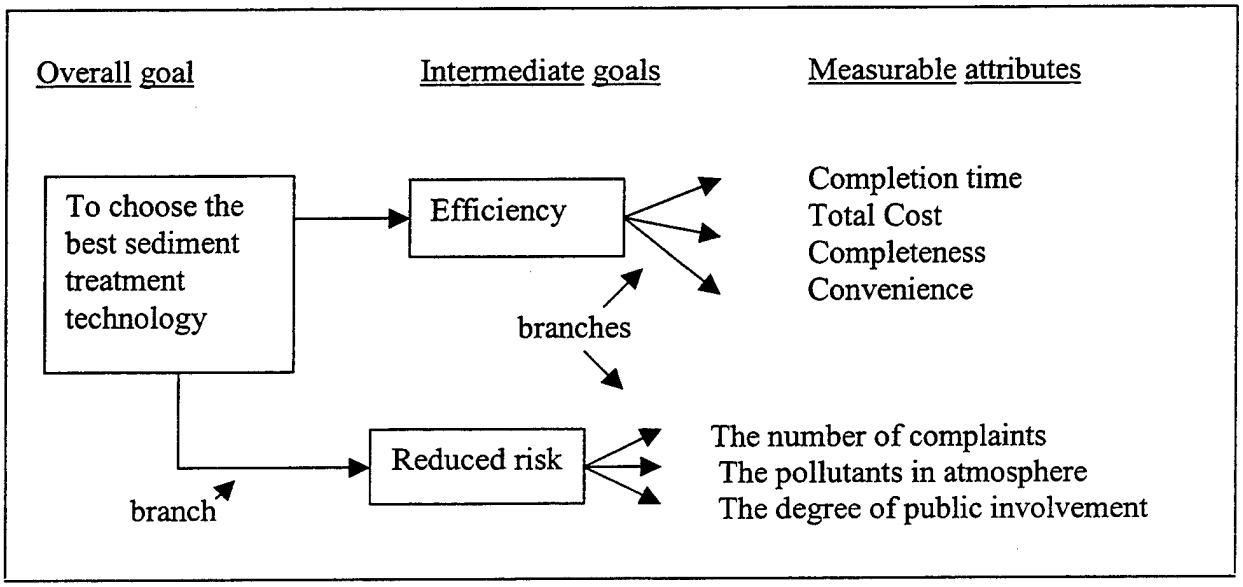


Figure 2.2. Value Tree Example.

### *a. Purpose of Using Value Trees*

Winderfeldt and Edwards (1986) explain three purposes for using value trees. First, value trees facilitate the process of ensuring that the final set of attributes actually captures all the relevant and useful values. Second, value trees identify the appropriate level of abstraction at which it is useful to carry out the evaluation. And third, value trees communicate concisely the entire spectrum of values and concerns of the decision-maker about the issue at hand.

### *b. Criteria for Evaluating Value Trees*

Keeney and Raiffa (1976) propose the following criteria for evaluating the objectives and the attributes in a value tree: completeness, operationality, decomposability, absence of redundancy, and minimum size. "Completeness requires that all relevant values be included in the superstructure of the tree, and the substructure completely defines the higher level values. Operationality requires that the lowest level values or attributes be meaningful and assessable. Decomposability means that the attributes can be analyzed one or two at a time, that is, that they are judgmentally independent. Absence of redundancy means that no two attributes or values mean the same thing. Minimum size requirement refers to the necessity of keeping the number of attributes small enough to manage." (Winderfeldt and Edwards, 1986, p. 43) However, the authors have found that these requirements do not always work together. The authors say, "These requirements conflict. Operationality often requires further decomposition, thus increasing the number of attributes. Completeness may lead to redundancy, since true value independence is often an unattainable ideal." (Winderfeldt and Edwards, 1986, p. 43)

### 3. Analytical Hierarchy Process (AHP)

In the 1970s, Thomas L. Saaty introduced an alternate method of solving multiple criteria problems called Analytic Hierarchy Process (AHP). AHP helps to solve the same problems for which MAUT is used: setting priorities, generating a set of alternatives, making decisions using benefits and costs, predicting outcomes (including risk assessment), measuring performance, ensuring system stability, and conflict resolution.

Thomas Saaty and Luis Vargas report that in decision-making, people provide subjective judgments based on feelings and intuition rather than on well-formulated logical reasoning (1991). "AHP should be used for problems involving a large number of attributes whose outcomes can only be measured on a relative scale." (Tiley, 1994, p. 27) The Analytical Hierarchy Process (AHP) demonstrates a representation of the mental process, by which overall judgments come about in situations involving complex goals and criteria. In "Prediction, Projection and Forecasting," (1991) Saaty and Vargas define AHP as a multi-objective, multi-criteria decision-making approach, which employs a pair-wise comparison procedure to arrive at a scale of preferences among sets of alternatives. The authors add that to apply the AHP approach, it is necessary to break down a complex unstructured problem into its component parts. The parts, or variables, are arranged into a hierarchic order; assign numerical values to subjective judgments on the relative importance of each variable; and synthesize the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome.

Saaty and Vargas continue by stating AHP is "intimately connected with the idea of consistency of thought. It [the process] admits inconsistency (including lack of

transitivity) and measures the effect of different levels of consistency on the results" (1991, p. 12) that are sought. Also, AHP "avoids aprioristic assumptions and models, and calls on the individual seeking to know, to construct the framework of that quest." (Saaty and Vargas, 1991, p. 12) The assumption in this thesis is that, judgment is based on the acquired experience, reason, and intuition. The objective of AHP is to "fulfill the purposes of the people concerned as well as possible, rather than to legislate to them that the outcome should be based on principles set for by other people, who are essentially outsiders to the problem. Thus, perceived constraints must be examined and not taken for granted – the only hope there is to plan a way out of difficult problems." (Saaty and Vargas, 1991, p. 12)

The AHP synthesizes two approaches by identifying the outcomes that are more beneficial to the actors, and at the same time, by providing a way of assessing the factors (causes) which may have more to do with certain types of outcomes.

In using AHP, objectives must be determined first: what needs to be done? Second, generate alternatives to satisfy those requirements: what are the possible ways of action? Third, set priorities according to the importance of the requirements that allow the implementation of the alternatives to attain some higher objective. Finally, choose the best policy alternative, or as in some cases, a mix of the best policy alternatives. The alternatives depend on the overall objective at hand. The choices may be either to allocate resources, assess the risk benefits and costs of the allocation, predict future consequences; or, measure the level of performance of the system, and possibly redesign the overall structure to fit the functions that must be performed to meet certain requirements. If the desire is to change the structure of a system, specific goals should be

achieved by implementation of specific policies. AHP can assist in structuring problems in a system, thereby assisting to prioritize the decision-maker's objectives.

AHP also has its pitfalls, such as rank reversal. Rank reversal refers to the concept of the alternative rankings that changes when new information is introduced into the problem (1994). The mathematical algorithms used in AHP may also be difficult to explain to those who are not mathematically inclined. In this thesis research, the need for legitimation precludes the use of AHP in favor of MAUT.

## D. SOLICITATION AND CONSENSUS BUILDING

### 1. Delphi Method

#### *a. Background*

For the purposes of this research, there is a need not only to elicit public values, but also to have a kind of consensus, a method to summarize the elicited values of several individuals. The Delphi technique is a method to meet these needs. Linstone and Turoff define the Delphi technique as "a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem." (1975, p. 3)

> The Delphi technique was developed during the 1950s by two researchers at the RAND Corporation as a procedure to 'obtain the most reliable consensus of opinion of a group of experts ...by a series of intensive questionnaires with controlled opinion feedback.' (Dalkey & Helmer, 1963) Initially, it [the Delphi] was used in the realm of long-term forecasts of change, particularly in science and technology. (Rowe, 1992)

In later years, many researchers have employed the Delphi technique in a variety of fields including determining the educational policies, predicting the future

technological problems, effects on society, and determining the future issues of real estate.

According to Rowe (1992), Delphi has four necessary characteristics: anonymity, iteration, controlled feedback and statistical aggregation of group response. Anonymity is achieved through the use of questionnaires which allow participants to respond privately. Anonymity reduces the influence of dominant individuals. Iteration of is the process of presenting the questionnaire over a number of rounds, which encourages respondents to change their minds. Controlled feedback takes place between rounds, in which each respondent is presented with the opinions of other respondents in the form of a statistical summary. At the end of the Delphi procedure, a statistical group response is obtained that illustrates the spread of opinion reflecting the degree of consensus on the issue.

### *b. The Delphi Process*

The Delphi process involves seven distinct tasks as shown in Figure 3. Creating the panels is the first critical task. Linstone and Turoff (1975) consider three kinds of panelists as ingredients for creating a successful mix: stakeholders; those who are or will be affected, experts, those who have an applicable specialty or relevant experience; and facilitators, those who have skills in clarifying, organizing, synthesizing, stimulating individuals who can supply alternative global views of the culture or society. Judging the desirability of individuals considered for the respondent group is subjective and therefore, according to some critics, is subject to mistake. However, subjectivity is a problem when formulating any group activity- committees, study groups, etc. The

problem is not unique to Delphi, and does not detract from the method usefulness. (Linstone and Turoff, 1975)

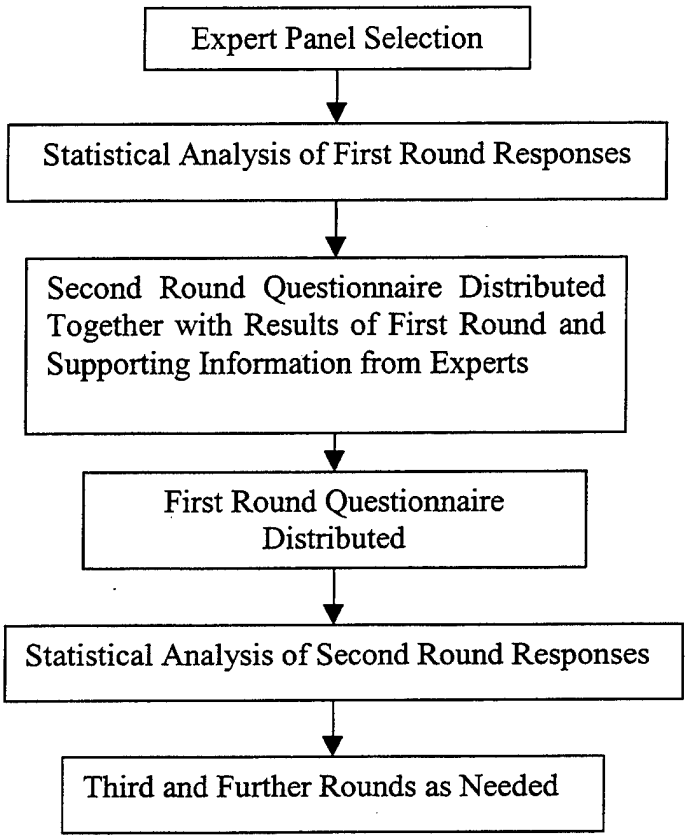


Figure 2.3. Delphi method (Kleindorfer, Kunreuther and Schoemaker, 1993 p. 234).

A questionnaire, prepared and distributed to participants, asks participants to provide their opinions that they see as being important. In this research, the respondents are asked to list the most important issues regarding the technology choice problem. "After the responses from the members are collected and all the redundant data is eliminated, the responses are then summarized statistically. At the end of round one, a second-round questionnaire is organized, which is entirely similar to the first-round

questionnaire, except that a statistical summary of first-round responses from the panel is also enclosed." (Kleindorfer, Kunreuther and Schoemaker, 1993, p. 236)

The second round questionnaire usually includes instructions, a statistical summary of first-round responses, and a section where the participants can provide any additional comments. Each summary statement has a corresponding scale so that each participant will rate all the statements.

Although this research uses an ordinal scale to rate statements, many Delphi research efforts make use of the Likert Scale, which is described below. The scale can have as the lower anchor, strongly disagree (SD) –2; and the higher anchor, strongly agree (SA) +2. Neutral (N) is assigned a zero value, disagree (D) and agree (A), -1 and +1, respectively. The zero point provides a neutral option to panel members and is intended to overcome forced-choice responding and provide members every possible option in rating. A threshold value can be set at the end such as statements rated below +1 rated statements will not be included in the next round. The purpose of the threshold value is to eliminate the extreme ideas. The responses of the participants at the end of this round are analyzed by utilizing the descriptive statistics. (Clayton, 1997)

In the third round, participants are provided the summarized data that is obtained at the end of round two. Group mean and individual ratings are provided to the participants so that each participant can see where his or her responses fall with respect to the measure of central tendency. Each member is then asked to re-rate the statements having the knowledge of opinions expressed in the previous round. Participants are also given the opportunity to provide their reasons to their ratings. The responses are

summarized again, and the participants are asked to re-rate the statements in the light of the new summary.

This process goes on until either a desired level of consensus is reached, or until a time constraint or other constraint is reached. Different authors agree that a successful Delphi can be carried out within a three-round format. "In practice, most Delphis on policy try to maintain a three- or four- round limit by utilizing the following procedure: (1) the monitor team devoting a considerable amount of time to carefully preformulating the obvious issues; (2) seeding the list with an initial range of options but allowing for the respondents to add to the lists; (3) asking for positions on an item and underlying assumptions in the first round." (Linstone and Turoff, 1975, p.88) Usually, the Delphi process stops when most of the responses indicate a consensus, or little change with further rounds is expected in the distribution of responses from participants. This research will conduct two rounds because of time constraints.

The above described Delphi methodology is called conventional Delphi. There are two other types of Delphi methods, real and policy. "Real-time Delphi differs from conventional Delphi in that, rather than taking weeks to conduct the process, it occurs during the course of a meeting or conference." (Clayton, 1997, p. 377) In the real-time Delphi, the monitor team is replaced by a computer, which has been programmed to carry out the compilation of the group results. This approach has the advantage of eliminating the delay caused in summarizing each round of Delphi, thereby turning the process into a real-time communication system." (Linstone and Turoff, 1975, p.5)

The Policy Delphi is a technique used to achieve "every possible opposing view" (Linstone and Turoff, 1975, p.84) on an issue. According to Clayton (1997), in

Policy Delphi, the decision-maker is not interested in having a group generate his decision, but rather in having and informed group present all the options and supporting evidence for his/her consideration. The policy Delphi is not a mechanism for making decisions as generating a consensus is not the prime objective. "A policy Delphi should be able to serve one or any combination of the following objectives: (1) to ensure that all possible options have been put on the table for consideration; (2) to estimate the effect of any particular option; (3) to examine and estimate the acceptability of each option." (Linstone and Turoff, 1975, p. 84)

The major strengths of Delphi are summarized as: Delphi technique helps to establish convergence of ideas over an issue. In Delphi, questionnaires can be sent to participants by mail or other means, eliminating the need to travel long distances to get together at the same place and time. Therefore, Delphi is cost effective. During implementation of Delphi, participants are required to provide their responses to the questionnaires privately. This process eliminates the negative effects of dominant groups, rank, personality, etc.

Linstone and Turoff (1975) identified inherent difficulties in the Delphi method. These include technical difficulties of re-adapting the method for each issue, the arbitrariness of panel members (respondents) selection, the balancing of closed and open-ended responses in the questionnaire, and estimating the time required for completion. At the end of each round, controlled feedback is provided to the respondents. In the process of feedback, limiting or eliminating some of the alternatives might have negative effects on the success of Delphi.

The number of respondents depends on the type, purpose and the complexity of the subject. According to Linstone and Turoff (1975), real-time Delphi and conventional Delphi can be given from a small to a large group and a policy Delphi can be given to a group ranging from ten to fifty people. This research is categorized as Policy Delphi, but utilizes fewer respondents than Linstone and Turoff suggested.

## E. AGGREGATION METHODS

Aggregation is used to measure the level of consensus derived from the Delphi method. Aggregation is defined as collecting inputs into a mass, yielding a collective output. It has been studied in mathematics, and has expanded into the decision sciences. When individual opinions are aggregated, the result is a single opinion, representing a group choice. Examples of basic aggregation methods include, mean, median, mode and Nominal Group Technique. Advanced methods presented in this section include the Hungarian method and Median Ranking method.

### 1. Basic Methods of Aggregation

Consider the following example of several Restoration Advisory Board (RAB) members listing various attributes in a Delphi forum. The panelists are comprised of seven different RAB members, each from a different location. The panelists define the attributes during the Delphi forum, and rank them in order of importance according to their respective RABs. No ties among the attributes are allowed (see Figure 4).

**RAB MEMBERS**

**ORDINAL RANKING**

| | RABA | RABB | RABC | RABD | RABE | RABF | RABG |
|---|---|---|---|---|---|---|---|
| Attribute 1 | 5 | 2 | 3 | 4 | 1 | 6 | 7 |
| Attribute 2 | 2 | 1 | 6 | 7 | 4 | 3 | 5 |
| Attribute 3 | 4 | 3 | 7 | 5 | 6 | 1 | 2 |
| Attribute 4 | 1 | 4 | 5 | 3 | 7 | 2 | 4 |
| Attribute 5 | 7 | 6 | 1 | 2 | 3 | 5 | 1 |
| Attribute 6 | 3 | 5 | 4 | 6 | 2 | 7 | 3 |
| Attribute 7 | 6 | 7 | 2 | 1 | 5 | 4 | 6 |

Figure 2.4. Example RAB Attribute Table.

Mean, also known as average, is the most common measure of location for a set of numbers. According to Wheeler and Chambers, average identifies the center of mass for the values in the data set (1992). Therefore, it can be considered the balance point among the data. The calculation of mean is fairly simple. It is the sum of all the values (In this example, the number represents the ordinal ranking of attributes, showing the relative importance of each attribute, i.e. 5 means 5$^{th}$ most important, 3 means 3$^{rd}$ most important, etc.) divided by the total number of values. Consider the above example: the total score of Attribute 1 is 28 (the sum of *5, 2, 3, 4, 1, 6, 7*). The mean is the sum of these seven values, divided by 7 (28/7 = 4). This value is the balance point for Attribute 1, and the mean values for Attributes 2 through 7 are presented in Figure 6. Therefore, if the RAB members decided the lowest number was the most desired, then Attribute 5 would be the best decision.

A median is another measure of location for a data set. This statistic identifies the 50th percentile of the data, indicating at least half the data are greater than, or equal to the median; and at least half the data are less than, or equal to the median. Therefore, while mean describes the balance point of the data set, median splits the data set into two equal halves. In calculating the median, the first step is to arrange the data set into numerical order (see Figure 5).

The revised example would be:

**MEDIAN**

| ATTRIBUTES | | | | | | | |
|---|---|---|---|---|---|---|---|
| Attribute 1 | 1 | 2 | 3 | **4** | 5 | 6 | 7 |
| Attribute 2 | 1 | 2 | 3 | **4** | 5 | 6 | 7 |
| Attribute 3 | 1 | 2 | 3 | **4** | 5 | 6 | 7 |
| Attribute 4 | 1 | 2 | 3 | **4** | 4 | 5 | 7 |
| Attribute 5 | 1 | 1 | 2 | **3** | 5 | 6 | 7 |
| Attribute 6 | 2 | 3 | 3 | **4** | 5 | 6 | 7 |
| Attribute 7 | 1 | 2 | 4 | **5** | 6 | 6 | 7 |

Figure 2.5. Defining the Term Median in the Example RAB Attribute Table.

Next, find the middle of this ordered data set. If the data set contains an odd number of values, there will be one middle value; if the set is even, there will be two middle values, and the median is calculated by averaging these two middle values. In the example, the data set contains a total of 7 values; therefore, the middle value for each attribute is listed in the 4th column (see Figure 5). The problem with this data set is there is a 4-way tie among the attributes, and the data set provided does not give an ordinal ranking, therefore the decision-makers do not know which attributes are ranked 1st, 2nd

and so on. The median method does not give the optimal solution; however, it explains where the RAB members have a general tendency towards an alternative, while not defining which alternative is optimal.

Mode is the measurement that occurs most frequently in the data set. Referring to Figure 6, the mode is identified for each attribute. Attributes 1, 2, and 3 do not have a mode; therefore, the decision-maker cannot rank this data set to derive the preferred choice among the RAB members.

When the decision-maker assigns equal importance among all the attributes, the simplest way to obtain an overall ranking is to total each row and rank them in ascending order (Yoon and Hwang, 1995). This technique is called the Nominal Group Technique, which provides an ordinal ranking of the alternatives; yet has its downfalls. First of all, it does not consider conflicting scores given by the RAB members. For example, in figure 4, RAB(A) ranks Attribute 4 as the best (score of 1) and RAB(E) ranks Attribute 4 as the worst (score of 7). This technique is a consensus building technique, where arithmetic operations do not provide the optimal solution, but presents a data set that every voting member can support. Figure 6 is a revised Delphi table listing the covered aggregation methods:

## 2. Advanced Methods of Aggregation

### *a. Median Ranking Method*

Median Ranking Method is used to measure the amount of agreement or disagreement among rankings. The method is done by a metric or distance function for the set of rankings. Median and consensus ranking is calculated by minimizing the total

absolute distance. Using the scores given in Figure 4, the method explained by Cook and Seiford (1978) follows.

There are 7 RAB members and 7 attributes. The formula that is used to derive a distance matrix is represented by

$$d_{ik} = \sum_{i=1}^{m} |a_i^l - k|,$$

| | | | | | MEDIAN | | | | TOTAL | | MODE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ATTRIBUTES | Attribute 1 | 1 | 2 | 3 | **4** | 5 | 6 | 7 | 28 | **4** | – | **3** |
| | Attribute 2 | 1 | 2 | 3 | **4** | 5 | 6 | 7 | 28 | **4** | – | **3** |
| | Attribute 3 | 1 | 2 | 3 | **4** | 5 | 6 | 7 | 28 | **4** | – | **3** |
| | Attribute 4 | 1 | 2 | 3 | **4** | 4 | 5 | 7 | 26 | **3.71** | **4** | **2** |
| | Attribute 5 | 1 | 1 | 2 | **3** | 5 | 6 | 7 | 25 | **3.57** | **1** | **1** |
| | Attribute 6 | 2 | 3 | 3 | **4** | 5 | 6 | 7 | 30 | **4.29** | **3** | **6** |
| | Attribute 7 | 1 | 2 | 4 | **5** | 6 | 6 | 7 | 31 | **4.43** | **6** | **7** |
| | | | | | | | | | | **MEAN** | | **NGT** |

Figure 2.6. Example RAB Attribute Table with Listings of Mean, Median, Mode and NGT.

where $d_{ik}$ represents the distance matrix, *k* defines the number of rankings (or, in the distance matrix, the column number). In this research, each RAB represents one ranking. The symbol *l* represents the number of members (in this case, RAB identification). The symbol *i* represents the number of attributes (or, in the distance matrix, the row number). The distance matrix is the sum of the deviations between a selected ranking (k) and the 7 given member rankings ($a_i^l$) of an attribute:

$$d_{11} = |5-1| + |2-1| + |3-1| + |4-1| + |1-1| + |6-1| + |7-1| = 21$$

$$d_{73} = |6-3| + |7-3| + |2-3| + |1-3| + |5-3| + |4-3| + |6-3| = 16$$

The complete calculation gives:

DISTANCE MATRIX ($d_{ik}$)

| | | | | | | |
|---|---|---|---|---|---|---|
| 21 | 16 | 13 | 12 | 13 | 16 | 21 |
| 21 | 16 | 13 | 12 | 13 | 16 | 21 |
| 21 | 16 | 13 | 12 | 13 | 16 | 21 |
| 21 | 16 | 13 | 12 | 13 | 16 | 21 |
| 19 | 14 | 12 | 10 | 13 | 18 | 23 |
| 18 | 15 | 14 | 15 | 16 | 19 | 24 |
| 23 | 16 | 11 | 10 | 11 | 14 | 19 |

Figure 1.7. Distance Matrix of RAB Ranked Attributes Using Median Ranking Method.

After calculating the distance matrix, the Hungarian method can be used to minimize the total distance. The output of the Hungarian method should give the optimal ranking.

### *b. Hungarian Method*

The output of the Median Ranking method is the input to the Hungarian method. The Hungarian method is used in minimization problems in operations science such as minimizing completion time of a project, minimizing total cost, or minimizing the total distance among attributes. Referring to the distance matrix in figure 7, the following steps are taken:

- For each row, subtract the minimum number in that row from all numbers in that row.
- For each column, subtract the minimum number in that column from all numbers in that column.
- Draw the minimum number of lines to cover all zeroes. If this number = m, stop. An assignment can be made.

- Determine the minimum uncovered number (call it *d*)

    a. Subtract *d* from uncovered numbers.

    b. Add *d* numbers covered by two lines.

    c. Numbers covered by one line remain the same.

    d. Then go to the previous step.

After completing the above steps, the distance matrix now looks like:

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 4 | 4 |
| 0 | 0 | 2 | 4 | 3 | 1 | 1 |
| 6 | 2 | 0 | 0 | 0 | 0 | 0 |
| 5 | 3 | 5 | 4 | 2 | 0 | 0 |

Figure 2.8. Minimization of the Distance Matrix.

The steps to determine the optimal solution are:

- Find a row or column with only one limited zero and circle it.

- If the circle is in a row with one zero, draw a line through its column. If the circle is in a column with one zero, draw a line through its row. One approach, when all rows and columns have two or more zeroes, is to draw a line through one with the most zeroes, breaking ties arbitrarily.

- Repeat the previous until all the circles are lined. If this minimum number of lines equals m, where m is the number of jobs and workers, then the circles provide the optimal assignment (htpp://isgs.ba.ttu.edu/classes/jburns/Tsq5342/slides/ch07).

The final outcome of the assignment problem using the Hungarian method is:

| Attribute | Rank | Score |
|---|---|---|
| 1 | 2 | 13 |
| 2 | 5 | 16 |
| 3 | 2 | 13 |
| 4 | 1 | 10 |
| 5 | 6 | 18 |
| 6 | 4 | 14 |
| 7 | 6 | 18 |

Figure 2.9. Assignment Matrix.

### 3. Assigning Weights to the Aggregated Ranking

Once the final ranking is determined through the Hungarian method, the decision-maker needs to compute the weights for the attributes with respect to one another. In other words, how much more important is the highest-ranked attribute to the second highest-ranked attribute? The "Smarter" method, used in a software program called Logical Decisions® for Windows™ (LDW), uses the final ranking from the aggregation method as its input, and a least preferred and most preferred level is given by the decision-maker to compute the weights for each attribute accordingly. For example, there are three attributes, project time, completeness and total cost, ranked as first and a tie for second respectively (see Figure 10).

| Attribute | Rank | Least Preferred Level | Most Preferred Level |
|---|---|---|---|
| Project time | 1 | 4 years | 1 year |
| Completeness | 2 | 50% | 100% |
| Total Cost | 2 | $10 Million | $1 Million |

Figure 2.10. Example of Assessment Using the "Smarter" Method.

The "Smarter" method will take the ranks and assign a higher weight to project time, and then, lower weights to completeness and total cost. For each choice sediment technology, there will be a level for each attribute listed in Figure 10. For example, sediment technology may take 3 years to be 80% complete, and a total cost of $7 million. The total utility score is calculated by the "Smarter" method with these figures and the rank of each attribute. After all utility scores are calculated for each sediment technology, the technology with the highest utility score is the optimal decision.

# III. DESIGN IMPLEMENTATION AND RESULTS

## A. INTRODUCTION

This chapter outlines the methodology used to implement Value Tree Analysis through the use of the Delphi Method conducted via the internet. The first four sections describe the research of applications used to create, manage and publish a website and survey, and use of a file transfer service to upload and download files to web servers. The fifth section discusses the formulation of roles of proxy-Restoration Advisory Board (RAB) members. The sixth section explains the implementation of the Delphi method via the internet-based discussion forum and survey. The process and results of the discussion phase and the two voting rounds are detailed. The last section provides the overall results of the survey experiment.

## B. WEBSITE DESIGN

### 1. Requirements

RABs need a common medium that provides access to sediment technology treatment information to educate themselves as well as others on important public issues, and to communicate their concerns and desires to public decision-makers. The instruction and the methodology information provided on the web provides another way to implement Delphi, which typically uses methods including conference meeting and mail out services in the first phase of execution. An electronic-based discussion forum provides proxy-RABs with the ability to post messages about their concerns, ask questions, read others' messages, reply to any posted message, and chat if they wish to do so. An advantage using internet and web technology is to allow the proxy-Restoration

Advisory Board (RAB) members to meet virtually to discuss and to post their comments, questions and responses at their convenience.

### 2. Website Design Tools and Free Web Server Providers

The authors of this research considered using several different website design tools to facilitate the Value Tree Analysis and the Delphi process. A brief discussion of the products considered is provided. Ultimately, the researchers selected Netscape® Composer, WS_FTP95, Xoom.com and Delphi.com for the research. Reasons for the choices are provided.

Microsoft® FrontPage® 98 is a tool to create the web site. "Microsoft® FrontPage® 98 consists of the FrontPage® Explorer (a site management tool), the FrontPage® Editor (an HTML processor), image composer (with which you can create and edit both still and animated graphics), and three web server programs (from which you choose depending on your platforms)" (Tauber and Kienen, 1998). Microsoft® FrontPage® 98 has the following capabilities:

- Creates and edits HTML easily, previews the page created and views the HTML source code
- Designs tables, resizes rows and columns quickly
- Includes forms where the data can be routed via e-mail or saved to a server
- Includes Microsoft® Office documents in HTML pages
- Includes text animation and other special effects
- Assigns permission to view and change various parts of the designer's site

Netscape® Composer is another tool used to create or edit web pages containing images, tables and links; and publishes the final drafted website on the web. Netscape®

Composer is easy to use, and its simplicity is similar to using a word processor. The files that the composer creates are HTML (Hypertext Markup Language) files just as Microsoft® FrontPage® creates. When the web pages (HTML files) are published on the web, the browsers know how to interpret the HTML codes to display HTML files.

Most of the Internet Server Providers (ISPs) include HTML editing tools to create a personal page. If the user is not a member of an ISP (such as America Online © 1999), there are many Free Web Service Providers (FWPs) available on the web to provide the necessary tools to create and host web sites for free.

FWP services are good if the number of pages created do not exceed fifty. Most FWP providers have limitations on certain web page features, such as computer hard drive space (see Table 3.1). Therefore, if the user desires to have a separate domain name, create hundreds of pages, use different web technologies (such as secure transactions), and expect high traffic capacity; then FWP cannot be used. For further information regarding free web providers, refer to http://netguide.com. FWP providers usually provide services including free e-mail, file management and File Transfer Protocol (FTP). FWP providers usually generate revenues through advertising.

| Free Web Service Provider | Hard Drive Space (MB) |
|---|---|
| Xoom | 11 |
| Crosswinds | Unlimited |
| AcmeCity | 20 |
| Angelfire | 5 |
| Hypermart | 10 |

Table 3.1. Examples of FWPs with Available Hard Drive Capacities.

Delphi Forums Inc., 1999, provides a free electronic medium for open discussion that allows members to create and manage personalized online forums. Delphi Forums provides a medium to connect and exchange ideas through a variety of full-featured, web-based messaging services. Visitors have the capability to browse through messages left by others, respond to previous postings, or start new conversations. Delphi Forums includes real chat and file attachment features. In addition, the designer of the forum has the ability to limit the access by designating the forum as a private website vice a public website. For more information regarding the use of Delphi Forums, visit its website at www.delphi.com.

This thesis project uses Delphi Forums because its services meet the requirements of this research. Delphi also provides tools to build a site homepage, which offers a link to the discussion forum. A limitation of Delphi Forums is the inability to allow more than one web page per website; therefore, another website provider is used to host links to the Delphi Forums homepage. The online forum is designed as a private website to allow only invited proxy-RAB members access to the forum. Proxy-RAB members are assigned unique usernames and passwords by the forum hosts.

On the advice of fellow Information Technology students, Xoom.com, Inc. 1997 is used for hosting the website created in this thesis research. The only requirement while registering with Xoom.com is to provide personal information including user name, e-mail address and affiliated company. To create the link pages, Netscape® Composer is used. After creating the desired web pages, the web designer publishes the web pages on a web server (Xoom.com).

This thesis research uses WS_FTP95 to upload the designed web pages (HTML pages) to the web server. To upload the web pages to the web server, the web designer must have access to the web server. During the uploading process, the FTP program asks the web designer to enter a profile name, host name, user name and password to be able to connect to the server and perform the necessary file transfers.

### 3. File Transfer Protocol (FTP)

"The most widely-deployed Internet file transfer service uses the FTP. FTP permits transfer of an arbitrary file, and includes a mechanism that allows files to have ownership and access restriction. A file transfer service can move a copy of a file from one computer to another, either interactively or in batch mode." (Comer, 1997, p. 347, 348)

FTP is based on the client-server model of communication between a server and a client computer. The server provides services such as transferring the requested information to the client computers. The client computers request information from the server. Non-government and government institutions usually have an FTP server to post their materials to the interested parties or individuals. In this thesis, an application of FTP is used to upload the HTML pages that are created.

## C. SURVEY TOOLS

This thesis research focuses on the subjective input of the stakeholders who are represented by proxy-RAB members. The importance of eliciting the concerns of members regarding the San Francisco Bay Sediment Project, and then allowing the group to rank the overall set of concerns ordinally, is required to utilize public opinion in the decision-making process. Currently, public representatives (RAB members) are asked to

attend local meetings, where discussion forums take place to identify the issues pertinent to the problem. The goals of utilizing a web survey are to eliminate the need for a physical meeting by conducting on-line discussions, and by eliciting issues over the internet.

### 1. Research Requirements

The survey tool must fulfill several functions. First the survey must provide an internet-based platform to perform the survey. Second, the tool must allow a large number of inputs by voting members. Third, the tool must allow members to rank the set of concerns (changed into attributes) in an ordinal manner. Fourth, the tool must provide the individual results of the survey to the survey host via email in text or database format, and finally, the tool must provide the entire service free of charge.

### 2. Alternative Survey Tools

The internet provides a host of websites that allow the users to develop surveys free of charge. However, the free survey providers have limited capabilities in questionnaire design, storage and publishing results. The following free internet providers and its capabilities are explained.

Delphi Forums, Inc. 1999 allows stakeholders to voice their opinions anonymously via internet discussion forum, the ability to rank a set of attributes is unavailable. Instead, Delphi Forums allows the forum host to list up to five choices, where the voting member may choose the most important choice alternative. In other words, the voting allowed in Delphi Forums allows the stakeholder to cast a vote in a ballot-type format. For more information regarding the use of Delphi Forums, visit the website at www.Delphi.com.

Perseus SurveySolutions™ *for the Web* is an application for creating and distributing surveys, as well as collecting, analyzing and reporting results. While some of the most common applications used by Perseus.com include customer and employer satisfaction surveys, course evaluations, and opinion polls, Perseus SurveySolutions™ *for the Web* also creates templates for lead generation forms, technical support inquiry forms, web-feedback questionnaires, and order forms. One of the most impressive features of Perseus SurveySolutions™ *for the Web* is its ability to produce instant survey results, making Perseus SurveySolutions™ *for the Web* ideal for publishing entertaining and informative polls on a personal web site. For more information regarding survey development with Perseus SurveySolutions™ *for the Web*, visit its website at www.Perseus.com.

This thesis research uses SurveySolutions™ *for the Web*, developed by Perseus Development Corporation. This tool uses an intuitive word-processing interface for survey design, and automates HTML translation for web-surveys and e-mail conversion for surveys that will be distributed by electronic mail. Survey responses are collected either on the server or on a workstation. Results can be stored in a variety of formats including standard ASCII TSV (tab separated values) files on the server and Microsoft access databases on your workstation. Perseus SurveySolutions™ *for the Web* also allows a free 30-day trial version, which allows this thesis to be conducted at no cost.

## D. FINAL WEBSITE AND SURVEY DESIGN

Upon choosing the free applications for creating, managing and publishing a website and survey, the creation of the NPS Sediment Project Home Page was formed

(www.delphi.com/nps_survey). The research homepage and the survey are shown in Figures 3.1 and 3.2.

# NPS Sediment Project Home Page

**Background of the Sediment Project:**

As a result of implementation of Base Realignment and Closure Commission (BRAC) decisions, the naval operations in the San Francisco Bay area has declined precipitously. Yet a legacy of the naval presence remains; portions of the Bay are contaminated from years of naval operations. The San Francisco Bay Sediment project is the U.S. Navy's program directed at redressing the contamination of sediment from the Bay area naval operations near: Mare Island, Hunters Point Shipyard, Alameda Point and Treasure Island. The project is administered by Engineering Facility Activity (EFA), West which is responsible for the project design as well as project execution. Two students at the Naval Postgraduate School have designed a communication process (that EFA, West can consider for implementation) that could help EFA, West elicit and utilize public concerns regarding site cleanup. The methodology is specifically aimed at assisting EFA, West officials in selecting the best remedy technology for each of the contaminated sites. The methodology, designed by the students, involves the public in the technology choice-decision making process and ensures that these concerns are a part of the decision-making for each site. For more information, please go to the link entitled "Methodology Information." Proxy-RAB members, those designated as participants in the methodology experiment, are instructed to read the "Methodology Information" before reading the "Instruction for Proxy-RABs" link.

**Relevant links:**

Message Board
Chat
Treatment Perspectives
NAVFAC Homepage
Navy's 5-year environmental restoration pgm
Sample Survey
Methodology Information
Instruction for Proxy-RABs
Survey-Phase2
Survey-Phase1 Results

Figure 3.1. NPS Sediment Project Home Page.

# NPS Pilot Sediment Project Survey

Please review and rank the following attributes according to your personal preference (1 = most important, 24 = least important). Do not assign any ties. Feel free to use the 'other' section to add any attribute you feel is important, but not included.
Thank you for your participation.

**Attributes.**

# of domestic pet deaths

# of domestic pet poisonings

# of civil lawsuits filed

# of complaints or protests

# of on-site injuries

Rate of medical treatments in area

# of birth defects in area

Amount of contaminant disposal

Distance of disposal site from residential area

Contaminants in air

Contaminants in soil

Quality of drinking water

Migration rate of drinking water

Availability for recreational boating/fishing

Total cost of site cleanup

Amount of total depreciation of land

# of fish/wildlife deaths

# of fish/wildlife poisonings

Consumable seafood?

Project completion time

Stability of foundation (after treatment)

Time for site to naturally restore itself

Future reuse for residential area?

Future reuse for business district?

**2.** Please provide any comments about your ranking. If you have an additional attribute that should be considered, list them in the below box and provide justification for its inclusion.

Figure 3.2. Survey used for Delphi Rounds I and II.

## E. IMPLEMENTATION OF DELPHI METHOD

The general steps of the Delphi method are outlined in the literature review chapter (Chapter 2, Section D.1.b). This section describes the actual methodology used in eliciting stakeholder value and aggregating the data to give a final ordinal ranking of the stakeholders' set of attributes for selecting the optimal sediment technology treatment.

### 1. Proxy-Restoration Advisory Board (RAB) Selection

The thesis researchers originally planned to use actual RAB members involved in the San Francisco Bay Sediment Project; however, time constraints and other commitments by EFA, West members limited their participation at this time. The available information about sediment treatment perspectives and NAVFAC's Five Year Restoration Program) is used to develop the proxy-RAB roles.

Proxy-RAB members with personal computers and internet access were chosen. Of the fourteen candidates originally requested to participate in the experiment, seven agreed to take a role as one of the seven panelists representing RABs from: Alameda Naval Air Station, Concord Naval Air Station, Mare Island Naval Shipyard, Moffett Field Naval Air Station, Treasure Island Naval Station, Treasure Island Naval Station Hunters Point Annex, Oakland Fleet and Industrial Supply Center. The panelists' demographic data include:

- O-5 Navy Flight Officer, stationed in Monterey, CA
- O-5 Marine Corps Reservist, stationed in Quantico, VA
- O-4 Retired Limited Duty Officer, residing in San Diego, CA

- O-3 Naval Advisor, stationed in Jacksonville, FL

- O-3 Judge Advocate General Officer, stationed in Bahrain

- O-3 Fleet Support Officer, stationed in Monterey, CA

- O-3 Civil Engineer Officer, station in Monterey, CA

Each panelist was emailed information specific to the site they represented. The roles of each RAB member are shown in Appendix B.

### 2. Discussion Phase of Delphi

As explained in the Literature Review Chapter, the goal of the discussion phase in the Delphi is to identify the public issues relevant to the San Francisco Bay Sediment Treatment Project (Chap. 2, Sect. D.1.a). The proxy-RAB panelists are given a period of one week to review their specific role, and to identify the issues which are considered important in selecting the best sediment treatment technology. The panelists are instructed to go to the *NPS Sediment Project Home Page* (www.delphi.com/nps_survey), where the panelists have access to background information and other relevant links regarding sediment restoration programs. Instructions for participating in the discussion phase of the Delphi are also given, and panelists are directed to use this electronic discussion forum to provide their concerns about the sediment treatment project. The leading question posted on the discussion forum is, "As a Restoration Advisory Board (RAB) member involved in the San Francisco Bay Sediment Project, what are the most important issues regarding sediment treatment? (Provide a minimum of 3 issues)" The unedited responses of the participating proxy-RAB panelists are shown in Appendix C. The results of the discussion phase are interpreted into measurable attributes, and

constructed into a value tree representing all the issues articulated by panelists relevant to selecting the best treatment technology.

Of the seven proxy-RAB panelists, only five responded to the discussion question. The five participants gave a total of 27 issues, 24 of which are relevant to choosing the best treatment technology. Figures 3.3 is the constructed value tree and Figure 3.4 summarizes the attributes articulated by the proxy-RAB panelists.

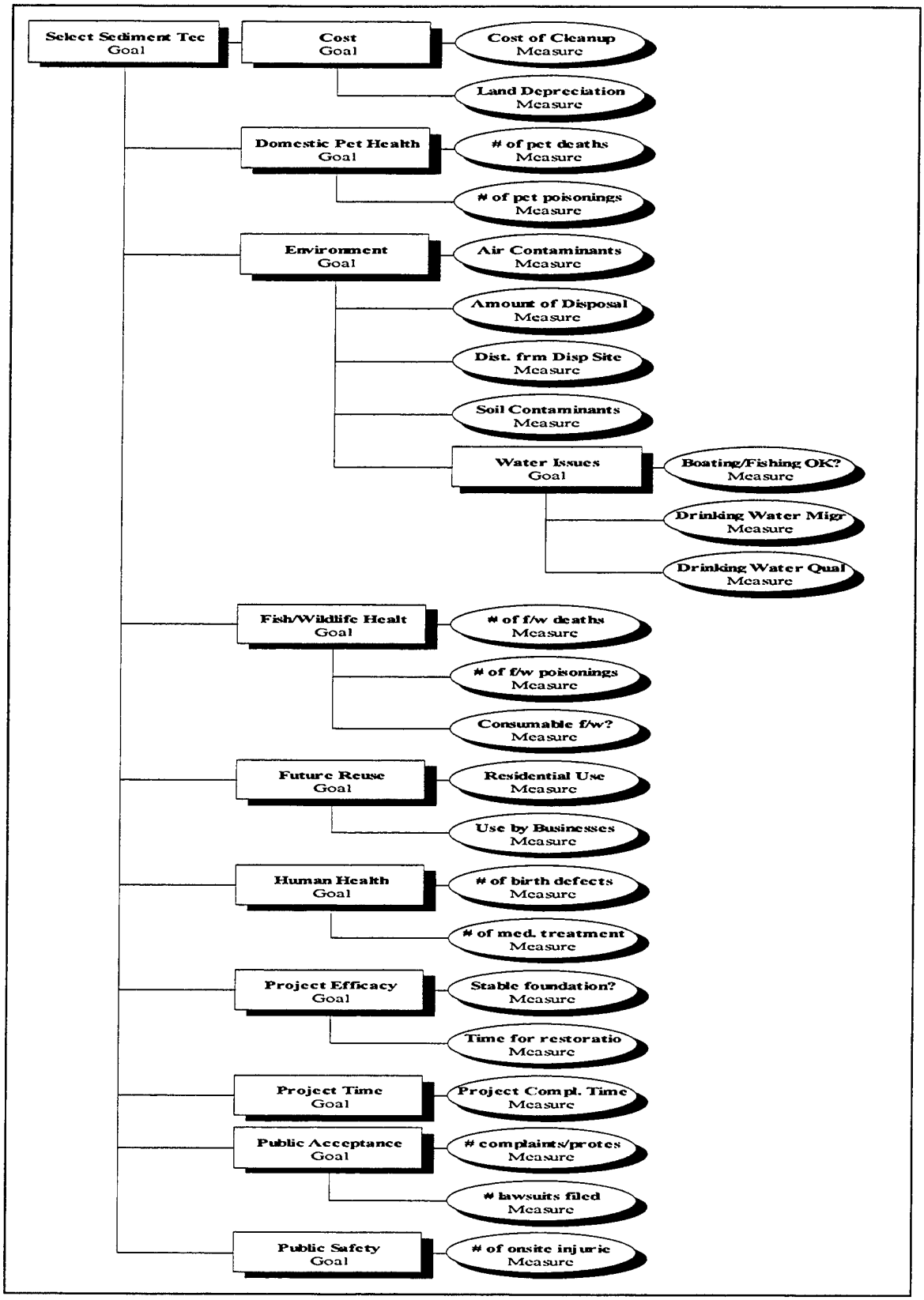


Figure 3.3. Value Tree Derived from Proxy-RAB.

## ISSUES PRESENTED BY PROXY-RAB PANELISTS

**# of domestic pet deaths:** How many pets have died as a result of exposure to the sediment treatment technology?

**# of domestic pet poisonings:** How many local pets can be infected with a disease if exposed to the sediment treatment technology?

**# of civil lawsuits:** How many class action lawsuits have been filed as a result of exposure to the combination of contaminants and sediment treatment technology?

**# of complaints or protests:** How many complaints have been filed or protests held in defiance to the sediment treatment technology?

**# of on-site injuries:** How many people are at risk of being physically injured during the sediment treatment project?

**Rate of medical treatments:** How many people will seek medical treatment for ailments such as cancer, respiratory problems or digestive problems as a result of the sediment treatment technology?

**# of birth defects:** How many newborn babies will be infected with a disease as a result of the sediment treatment technology?

**Amount of contaminant disposal:** What is an acceptable amount of contaminants that can exist without causing any ill effects on the San Francisco Bay?

**Distance of disposal site from residential area:** How far does the disposal site have to be to not affect the San Francisco Bay area?

**Contaminants in air:** What is EPA's acceptable level of contaminants in the air?

**Contaminants in soil:** What is EPA's acceptable level of contaminants in the soil?

**Quality of drinking water:** After treatment, will the water be potable or non-potable?

**Migration rate of drinking water:** Since there is a possibility of contaminant runoff in the water, how much of the natural drinking water will be affected by the sediment treatment technology?

**Availability for recreational boating/fishing:** Will the waters of the San Francisco Bay be safe enough to permit recreational boating and fishing?

**Total cost of site cleanup:** What is the total cost for the sediment treatment technology?

**Amount of total depreciation:** After the sediment treatment technology has been applied, how much will the land depreciate in its market value?

**# of fish/wildlife deaths:** How many fish/wildlife have died as a result of exposure to the sediment treatment technology?

**# of fish/wildlife poisonings:** How many local fish/wildlife can be infected with a disease if exposed to the sediment treatment technology?

**Is seafood consumable?** Will the seafood in the San Francisco Bay be consumable?

**Project completion time:** How long will it take for complete restoration of the sediment?

**Stability of foundation after treatment:** Has the contamination and proposed treatment affected the stability of the soil to support the foundation of future building in the area?

**Time for site to naturally restore itself:** How much time will it take for the sediment to restore itself after the treatment technology has been applied?

**Future reuse for residential area:** After completion of the restoration, will the treated areas be suitable for building a residential community?

**Future reuse for businesses:** After completion of the restoration, will the treated areas be suitable for building businesses?

Figure 3.4. Attributes articulated by proxy-RAB members for the Restoration Project.

### 3. Delphi – Round I

At the conclusion of the discussion phase, where proxy-RAB panelists articulate their relevant values (i.e. attributes), proxy-RAB panelists are asked to participate in the Survey-Phase I. The panelists are instructed to rank each attribute in an ordinal manner (1 = most important, 24 = least important), with no ties allowed. The panelists are given

three days to rank the attributes. Panelists are encouraged to refer back to the message board to understand each other's opinion better before ranking.[3]

Of the seven proxy-RAB panelists, only four participated in Round 1 of the Delphi. The results are summarized on a spreadsheet, where each attribute's mean and standard deviation are calculated. The original plan to use the Median Ranking and Hungarian Methods to aggregate the ordinal rankings proved to be unsuccessful. A requirement for using the Hungarian Method is to have a square matrix, consisting of $m$ rows and $m$ columns. To achieve a square matrix, the original distance matrix (given by the Median Ranking Method) should be supplemented with dummy zeros. The small number of responses (four) versus the large number of attributes (24) calls for 20 columns of zero values. After applying the steps of the Hungarian Method to the Median Ranking Method, only four attributes are distinguished as being more important than the remaining 20 attributes; and of those four attributes, no specific ranking could be determined. The remaining 20 attributes could be ranked in an arbitrary manner, which does not provide a desired overall ranking for the attributes. Therefore, after collecting the input of each proxy-RAB member, the mean value is calculated for the rank given to each attribute, and a standard deviation is calculated for each attribute to determine the distance from the respective mean. The results of the first round of Delphi are listed in Table 3.2.

[3] On the third day of Round 1, the host received a message that the survey server would not accept the inputs of the proxy-RAB panelists. The survey was reformatted for the web, and re-published within hours. Due to this problem, an extra day is given for proxy-RAB members to rank the attributes.

### 4. Delphi – Round II

In this round, the final ordinal ranking and a summary of Delphi Round 1 is published. One proxy-RAB panelist did not provide justification for his or her ranking in Round 1, and was asked to provide comments on the electronic message board. Panelists are encouraged to exchange information on the message board to educate each other, and at times defend their rationale for ranking the attributes.

Next, proxy-RAB panelists are invited to participate in Delphi Round II, and are given two days to re-evaluate their personal ranking with that of the overall group ranking, and provide a second ranking with justification. Of the seven proxy-RAB panelists, five responded.[4] The results of Delphi Round II are aggregated by determining the mean and standard deviation of each attribute. The final ordinal ranking of attributes are provided in Table 3.3.

## F. RESULTS SUMMARY

The objective of this section is to determine the degree of association between Delphi Rounds I and II. Determining the degree of association between the rounds is important because it confirms whether a group is converging towards an overall ranking of the set of attributes.

In this thesis project, the mean value was calculated for each round because of the difference in the number of participants in each round of Delphi (four panelists in the first round, and five in the second round). This survey could not utilize the Nominal Group Technique (NGT) because the total for each attribute would increase in the second round

[4] The Perseus server was down for two hours on the second day, and results could not be collected as scheduled; therefore, extra time was given for input.

by a value (given by the fifth panelist), thereby providing no level of convergence among the attributes.

To determine the level of convergence of the rankings in Delphi Rounds I and II, the correlation of the mean values and standard deviations are taken. Since the calculation of the correlation provides a number close to one, it can be summarized that the mean ranking for each attribute in Delphi Round II are closely associated to the results obtained in Delphi Round I. In addition to the overall correlation obtained in the average rankings for each attribute in Delphi Rounds I and II, the average standard deviation associated with the rankings of the attributes declined in Delphi Round II, indicating more agreement among the ranks given by the proxy-RAB panelists. As a crosscheck to measure the degree of convergence between Delphi Rounds I and II, a rank correlation test is applied to the rank data, to find Spearman's rank correlation coefficient (R). The result of 0.94 indicates correlation in Delphi Rounds I and II, where Delphi Round I has a positive influence on the ranking obtained in Delphi Round II. Because of the influence, this thesis can conclude that after two rounds of Delphi, the proxy-RAB panelists grew closer to consensus, and that further rounds would continue to produce high correlation coefficients close to one. Table 3.4 provides the overall correlation of the two Delphi rounds, and lists the convergence (if any) for the ranking of each attribute.

## G. ASSIGNING WEIGHTS TO THE ATTRIBUTES

In Appendix A, different methods are explained to assign weights to the attributes. As a result of the implementation of the Delphi and aggregation methods, the final ordinal ranking of attributes are obtained. The rank sum weighting or rank reciprocal weighting methods are used to assign weights to the attributes. Both

techniques are approximations where the decision-maker may choose his or her method of preference. Furthermore, the researchers made the assumption that the degree of importance between each attribute is equal, as they are ranked ordinally. The assumption, although not one hundred percent theoretically defendable, was made to simplify the process. The results are thought not to be affected, while the assumption makes the process easier to legitimate to the stakeholders. The weights of the attributes are calculated and listed in Table 3.5.

**Phase 1 - Survey Results**

| | RABA | RABB | RABC | RABD | SUM | Average | STD | Rank1 |
|---|---|---|---|---|---|---|---|---|
| # of domestic pet deaths | 6 | 11 | 16 | 14 | 47 | 11.75 | 4.349329 | 11 |
| # of domestic pet poisonings | 5 | 10 | 17 | 15 | 47 | 11.75 | 5.377422 | 11 |
| # of civil lawsuits filed | 24 | 23 | 24 | 24 | 95 | 23.75 | 0.5 | 24 |
| # of complaints or protests | 23 | 24 | 2 | 16 | 65 | 16.25 | 10.14479 | 18 |
| # of on-site injuries | 15 | 2 | 10 | 1 | 28 | 7 | 6.683313 | 5 |
| Rate of medical treatments | 2 | 7 | 11 | 3 | 23 | 5.75 | 4.112988 | 3 |
| # of birth defects | 1 | 1 | 12 | 4 | 18 | 4.5 | 5.196152 | 2 |
| Amount of contaminant disposal | 13 | 8 | 19 | 18 | 58 | 14.5 | 5.066228 | 15 |
| Distance of disposal site from residential | 14 | 16 | 20 | 11 | 61 | 15.25 | 3.774917 | 16 |
| Contaminants in air | 8 | 4 | 3 | 8 | 23 | 5.75 | 2.629956 | 3 |
| Contaminants in soil | 9 | 6 | 6 | 17 | 38 | 9.5 | 5.196152 | 7 |
| Quality of drinking water | 7 | 3 | 4 | 2 | 16 | 4 | 2.160247 | 1 |
| Migration rate of drinking water | 11 | 5 | 5 | 19 | 40 | 10 | 6.63325 | 9 |
| Availability for recreational boating/fishing | 12 | 15 | 8 | 20 | 55 | 13.75 | 5.057997 | 14 |
| Total cost of site cleanup | 21 | 22 | 21 | 13 | 77 | 19.25 | 4.193249 | 23 |
| Amount of total depreciation | 22 | 14 | 18 | 21 | 75 | 18.75 | 3.593976 | 22 |
| # of fish/wildlife deaths | 4 | 13 | 13 | 5 | 35 | 8.75 | 4.924429 | 6 |
| # of fish/wildlife poisonings | 3 | 12 | 15 | 12 | 42 | 10.5 | 5.196152 | 10 |
| Is seafood consummable? | 10 | 9 | 14 | 6 | 39 | 9.75 | 3.304038 | 8 |
| Project completion time | 20 | 17 | 23 | 10 | 70 | 17.5 | 5.567764 | 20 |
| Stability of foundation after treatment | 18 | 19 | 1 | 23 | 61 | 15.25 | 9.742518 | 16 |
| Time for site to naturally restore itself | 16 | 18 | 22 | 9 | 65 | 16.25 | 5.439056 | 18 |
| Future reuse for residential area | 17 | 20 | 7 | 7 | 51 | 12.75 | 6.751543 | 13 |
| Future reuse for businesses | 19 | 21 | 9 | 22 | 71 | 17.75 | 5.965177 | 21 |
| | | | | | | Sum | 121.5606 | |
| | | | | | | Average | 5.065027 | |

Table 3.2. Results of Delphi Round I

**Phase 2 - Survey Results**

| RABA | RABB | RABC | RABD | RABE | SUM | Average | STD | Rank2 |
|---|---|---|---|---|---|---|---|---|
| 12 | 6 | 11 | 8 | 11 | 48 | 9.6 | 2.5099801 | 8 |
| 10 | 7 | 12 | 9 | 12 | 50 | 10 | 2.1213203 | 9 |
| 24 | 24 | 24 | 20 | 24 | 116 | 23.2 | 1.7888544 | 24 |
| 23 | 23 | 19 | 21 | 15 | 101 | 20.2 | 3.3466401 | 22 |
| 6 | 17 | 3 | 7 | 23 | 56 | 11.2 | 8.4380092 | 12 |
| 8 | 2 | 6 | 3 | 5 | 24 | 4.8 | 2.3874673 | 4 |
| 2 | 1 | 2 | 2 | 6 | 13 | 2.6 | 1.9493589 | 2 |
| 9 | 16 | 16 | 11 | 14 | 66 | 13.2 | 3.1144823 | 13 |
| 16 | 15 | 17 | 12 | 13 | 73 | 14.6 | 2.0736441 | 16 |
| 3 | 8 | 7 | 4 | 1 | 23 | 4.6 | 2.8809721 | 3 |
| 5 | 9 | 14 | 5 | 4 | 37 | 7.4 | 4.1593269 | 5 |
| 1 | 3 | 1 | 1 | 2 | 8 | 1.6 | 0.8944272 | 1 |
| 7 | 14 | 8 | 10 | 3 | 42 | 8.4 | 4.0373258 | 6 |
| 14 | 13 | 15 | 16 | 8 | 66 | 13.2 | 3.1144823 | 13 |
| 22 | 18 | 21 | 18 | 22 | 101 | 20.2 | 2.0493902 | 22 |
| 15 | 21 | 22 | 22 | 20 | 100 | 20 | 2.9154759 | 21 |
| 13 | 4 | 4 | 14 | 9 | 44 | 8.8 | 4.7644517 | 7 |
| 11 | 5 | 10 | 15 | 10 | 51 | 10.2 | 3.5637059 | 10 |
| 4 | 10 | 9 | 23 | 7 | 53 | 10.6 | 7.3006849 | 11 |
| 19 | 19 | 20 | 19 | 21 | 98 | 19.6 | 0.8944272 | 20 |
| 18 | 20 | 23 | 13 | 16 | 90 | 18 | 3.8078866 | 19 |
| 17 | 22 | 5 | 24 | 19 | 87 | 17.4 | 7.436397 | 18 |
| 20 | 11 | 13 | 6 | 17 | 67 | 13.4 | 5.4129474 | 15 |
| 21 | 12 | 18 | 17 | 18 | 86 | 17.2 | 3.2710854 | 17 |
| 300 | 300 | 300 | 300 | | | | 84.232743 | |
| | | | | | | Sum | 84.232743 | |
| | | | | | | Average | 3.5096976 | |

Table 3.3. Results of Delphi Round II

## OVERALL RESULTS

| | ROUND 1 | | | ROUND 2 | | | |
|---|---|---|---|---|---|---|---|
| | Average Rank | StdDev | Overall Rank(X) | Average Rank | StdDev | Overall Rank(Y) | (X-Y)^2 |
| # of domestic pet deaths | 11.75 | 4.34932945 | 11.5 | 9.6 | 2.50998008 | 8 | 12.25 |
| # of domestic pet poisonings | 11.75 | 5.377421935 | 11.5 | 10 | 2.12132034 | 9 | 6.25 |
| # of civil lawsuits filed | 23.75 | 0.5 | 24 | 23.2 | 1.78885438 | 24 | 0 |
| # of complaints or protests | 16.25 | 10.1447852 | 18.5 | 20.2 | 3.34664011 | 22.5 | 16 |
| # of on-site injuries | 7 | 6.683312552 | 5 | 11.2 | 8.43800924 | 12 | 49 |
| Rate of medical treatments | 5.75 | 4.11298756 | 3.5 | 4.8 | 2.38746728 | 4 | 0.25 |
| # of birth defects | 4.5 | 5.196152423 | 2 | 2.6 | 1.94935887 | 2 | 0 |
| Amount of contaminant disposal | 14.5 | 5.066228051 | 15 | 13.2 | 3.1144823 | 13.5 | 2.25 |
| Distance of disposal site from residential area | 15.25 | 3.774917218 | 16.5 | 14.6 | 2.07364414 | 16 | 0.25 |
| Contaminants in air | 5.75 | 2.62995564 | 3.5 | 4.6 | 2.88097206 | 3 | 0.25 |
| Contaminants in soil | 9.5 | 5.196152423 | 7 | 7.4 | 4.15932687 | 5 | 4 |
| Quality of drinking water | 4 | 2.160246899 | 1 | 1.6 | 0.89442719 | 1 | 0 |
| Migration rate of drinking water | 10 | 6.633249581 | 9 | 8.4 | 4.03732585 | 6 | 9 |
| Availability for recreational boating/fishing | 13.75 | 5.057996968 | 14 | 13.2 | 3.1144823 | 13.5 | 0.25 |
| Total cost of site cleanup | 19.25 | 4.193248542 | 23 | 20.2 | 2.04939015 | 22.5 | 0.25 |
| Amount of total depreciation | 18.75 | 3.593976442 | 22 | 20 | 2.91547595 | 21 | 1 |
| # of fish/wildlife deaths | 8.75 | 4.924428901 | 6 | 8.8 | 4.7644517 | 7 | 1 |
| # of fish/wildlife poisonings | 10.5 | 5.196152423 | 10 | 10.2 | 3.56370594 | 10 | 0 |
| Is seafood consummable? | 9.75 | 3.304037934 | 8 | 10.6 | 7.3006849 | 11 | 9 |
| Project completion time | 17.5 | 5.567764363 | 20 | 19.6 | 0.89442719 | 20 | 0 |
| Stability of foundation after treatment | 15.25 | 9.742518497 | 16.5 | 18 | 3.80788655 | 19 | 6.25 |
| Time for site to naturally restore itself | 16.25 | 5.439056291 | 18.5 | 17.4 | 7.43639698 | 18 | 0.25 |
| Future reuse for residential area | 12.75 | 6.751543034 | 13 | 13.4 | 5.41294744 | 15 | 4 |
| Future reuse for businesses | 17.75 | 5.965176723 | 21 | 17.2 | 3.27108545 | 17 | 16 |
| | **Average** | **5.065026627** | | **Average** | **3.50969764** | | 137.5 |
| | | | | | | | 24 |
| | | **OVERALL** | | | **OVERALL** | | |
| | | **Correlation** | 0.938029 | | **Rank** | | |
| | | **diff in StdDev** | **-1.55533** | | **Correlation** | 0.940217 | |

Table 3.4. Overall Results of Delphi

**ASSESSMENT OF WEIGHTS**

| | Inverse Rank | Rank Sum Weight | Normal Rank | Reciprocal of Normal Rank | Rank Reciprocal Weight |
|---|---|---|---|---|---|
| # of domestic pet deaths | 17 | 0.0567 | 8 | 0.1250 | 0.0331 |
| # of domestic pet poisonings | 16 | 0.0533 | 9 | 0.1111 | 0.0294 |
| # of civil lawsuits filed | 1 | 0.0033 | 24 | 0.0417 | 0.0110 |
| # of complaints or protests | 2.5 | 0.0083 | 22.5 | 0.0444 | 0.0118 |
| # of on-site injuries | 13 | 0.0433 | 12 | 0.0833 | 0.0221 |
| Rate of medical treatments | 21 | 0.0700 | 4 | 0.2500 | 0.0662 |
| # of birth defects | 23 | 0.0767 | 2 | 0.5000 | 0.1324 |
| Amount of contaminant disposal | 11.5 | 0.0383 | 13.5 | 0.0741 | 0.0196 |
| Distance of disposal site from residential area | 9 | 0.0300 | 16 | 0.0625 | 0.0166 |
| Contaminants in air | 22 | 0.0733 | 3 | 0.3333 | 0.0883 |
| Contaminants in soil | 20 | 0.0667 | 5 | 0.2000 | 0.0530 |
| Quality of drinking water | 24 | 0.0800 | 1 | 1.0000 | 0.2649 |
| Migration rate of drinking water | 19 | 0.0633 | 6 | 0.1667 | 0.0441 |
| Availability for recreational boating/fishing | 11.5 | 0.0383 | 13.5 | 0.0741 | 0.0196 |
| Total cost of site cleanup | 2.5 | 0.0083 | 22.5 | 0.0444 | 0.0118 |
| Amount of total depreciation | 4 | 0.0133 | 21 | 0.0476 | 0.0126 |
| # of fish/wildlife deaths | 18 | 0.0600 | 7 | 0.1429 | 0.0378 |
| # of fish/wildlife poisonings | 15 | 0.0500 | 10 | 0.1000 | 0.0265 |
| Is seafood consummable? | 14 | 0.0467 | 11 | 0.0909 | 0.0241 |
| Project completion time | 5 | 0.0167 | 20 | 0.0500 | 0.0132 |
| Stability of foundation after treatment | 6 | 0.0200 | 19 | 0.0526 | 0.0139 |
| Time for site to naturally restore itself | 7 | 0.0233 | 18 | 0.0556 | 0.0147 |
| Future reuse for residential area | 10 | 0.0333 | 15 | 0.0667 | 0.0177 |
| Future reuse for businesses | 8 | 0.0267 | 17 | 0.0588 | 0.0156 |
| **SUMS** | 300 | 1 | | 3.7757 | 1 |

Table 3.5. Assigning Weights to the Attributes

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# IV. CONCLUSION AND RECOMMENDATIONS

Based on the results achieved in the implementation phase of this thesis, the following lessons learned are identified. The lessons concern the participation level of proxy-RAB members, the articulated attributes collected, and the effectiveness of the internet.

First, any implementation of the internet-based Delphi should not expect 100% participation. This thesis research originally planned to use seven panelists to participate in its survey; however only four and five panelists participated in the first and second rounds respectively. The anonymity feature of the Delphi method may actually restrict the participants' accountability in contributing to the discussions and ranking the attributes. In a typical Delphi, participants gather in a conference room and submit their votes. While the votes are anonymous, there is an assumption that each member submits a vote, since the effort to convene at a physical location makes the act of voting a small marginal effort. Due to the expected decrease in the participation rate over the internet, a recommendation may be to invite twice the number of panelists to obtain the desired input level.

Second, since proxy- Restoration Advisory Board (RAB) members are used in the survey, the results might not reflect an accurate selection of issues related to the San Francisco Bay Sediment Project. Remediation technology selection is a technical subject and, with the exception of one panelist, the proxy-RAB members do not have the desired knowledge to participate this type of survey for reasons such as geographic location, real sediment issues in the San Francisco Bay area, and the actual objectives of existing

RABs. Better survey results can be obtained by using real stakeholders, and having technical experts available to answer any treatment-specific questions.

Third, the flexibility introduced into the process by using the internet to facilitate the Delphi has positive and negative implications. The use of the internet allows for broader participation since participants are not constrained by geographic locality or time. However, this thesis research has found the internet-based Delphi method to require more time than the traditional Delphi method. Because participants rarely participate concurrently, panelists are required to visit the forum more than once to read the responses of others and to provide any additional comments.

Fourth, the level of technicality may also influence the time it takes to complete the Delphi method. Highly complex issues may be easier to explain with traditional methods such as physical proximity. If the subject is technical, more time may be taken to educate and elicit values concerning the discussion topic. When the panelists meet physically, the exchange of information occurs much faster than by posting messages on an electronic bulletin board, and the technical subjects can be explained better by using visual aids to make a point. Also, there may be some hesitancy by some to utilize the internet. Techno-phobia may limit the usefulness of the internet.

Online chatting is a viable option to use during the discussion phase of the Delphi method. Although proxy-RAB members have the ability to use the chat feature, the feature was not utilized by the members in this thesis research. This may be for a variety of reasons including time constraints and number of RAB participants. The time of day that proxy-RAB members choose to participate may not be the optimal time for others. This thesis research includes panelists from three different time zones (one being

overseas); therefore, the likelihood of the panelists being online at the same time is difficult.

The Delphi survey results show that the Delphi established consensus through a degree of association. The ordinal ranking of round two is closely associated with the ordinal ranking of round one and the standard deviation of many of the attributes at round two decreased relative to round one. If one or more additional rounds of Delphi are conducted, more consensus might have been obtained.

During the creating of the survey and gathering data, several difficulties were experienced. One of the difficulties was formatting the questionnaire. Due to the wrong formatting, panelists were unable to submit their responses for two days. Only after receiving a warning message from Perseus Corporation were the authors able to identify the problem and solve it. The survey server unexpectedly ceased operations for several hours, which the researchers have learned is fairly common with the use of free internet tools. Given the limited experiences from this research, the authors concluded that the services of Free Web Service providers might not be reliable enough to meet the requirements of organizations. The use of free internet tools and servers should be considered carefully. Non-government and government institutions should have control of the server and not depend on others for full-time uninterrupted service.

At the end of Delphi Round I, proxy-RAB panelists identified public awareness as an issue that should be considered in the San Francisco Bay Sediment project. Since this does not relate directly to the choosing the optimal treatment technology, it is not included in the value tree. There is concern by the panelists, however, as to how the public will be informed about the issues, results, remediation technologies, and updates

on the sediment treatment projects. This point re-confirms the importance of this thesis research and its goal of including public involvement and awareness, and of gathering public opinion into a value tree that can be used by decision-makers to make the optimal decision. It also confirms that the public does have a concern with the decisions made, and with the gathering of public opinion, decision-makers are better prepared to legitimate their choice to the public.

The original plan of using the Median Ranking and the Hungarian method changed during the implementation phase. After numerous attempts of applying the Hungarian method to the data, the researchers found that it is impossible to use a matrix that is made up primarily of zeros. The Hungarian method uses the distance matrix derived in the Median Ranking method, and because the Hungarian method requires a square matrix or a matrix close to a square matrix, an assignment could not be derived from the distance matrix calculated in this research.[5] Therefore, the basic methods of aggregation and statistical methods including standard deviation and correlation coefficients are used.

The use of the internet is a viable method in eliciting public values; however, there are issues that should be considered. If an organization wants to gather public opinion from people living in a certain area, the organization may have problems in access control to only allow local residents to participate. Another issue is if the number of people involved is relatively high, then the results should be stored in the database. This requires web database interaction, and presents a new opportunity for thesis work.

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[5] See section E.3 of the Implementation and Results Chapter.

# APPENDIX A. ADDITIVE UTILITY FUNCTION AND MULTIATTRIBUTE UTILITY THEORY (MAUT)

## A. VALUE AND CHOICE

In his book, "Making Hard Decisions," (1996) Clemen argues, "the basic reason for using a utility function as a preference model in decision-making is to capture our attitudes about risk and return." (p. 530) Risk and return are considered elementary objectives in decision-making, and usually conflict with one another when pursuing high returns while minimizing risk. Clemen (1996) provides an example of a mayor deciding whether to approve or disapprove a new electric power generating station. The known factors in this situation include the fact that the city needs more power capacity; but, building the new plant would worsen the city's air quality. The mayor might consider: health of residents, economic conditions of the residents, psychological state of the residents, economy of the city and the state, businesses, and local politics.

A preference model can assist the decision-maker (in this case, the mayor) to select a single alternative from a set of feasible alternatives. Consensus building could be used, which provides a simple way of prioritizing the issues in a manner, which the decision-makers can support; however, more mathematical methods of aggregation may be preferred.

### 1. Objectives

Decision analysis has been used successfully to construct and solve problems for numerous situations. The analysis is based upon choosing a solution approach that lists the decision-maker's objectives, and assigns a weight according to its importance. When

there are two or more conflicting objectives, an additive preference model may be used to calculate a utility score associated with each objective. These objectives are weighted appropriately, according to the relative importance to each other, and then added together to give an overall solution to the problem.

### *a. Fundamental versus Means Objectives*

To develop a structured decision-making process, objectives for solving the problem must be defined. Objectives can be thought of as a "desired end-state resulting from planning activity," (Kleindorfer, Kunreuther and Schoemaker, 1993, p. 36) and can be labeled as either fundamental objectives or means objectives.

Fundamental Objectives are objectives that the decision-maker wants to accomplish. Means Objectives are objectives that help accomplish the fundamental objectives by defining measured attributes. For example, "working fewer hours may appear to be an important objective, but it may be important only because it would allow an individual to spend more time with his or her family or to pursue other activities that represent fundamental interests, things that are important simply because they are important. Thus, *minimize hours worked* is a means objective, whereas *maximize time with family* is a fundamental objective." (Clemen, 1996, p. 44)

Attributes are important in explaining and quantifying the higher level values and concerns, and are defined as the criteria for measuring objectives. According to Rowe (1992), an attribute is the quantity measured on an attribute scale. Attribute scales are used as a tool to measure the accomplishment level of the fundamental objectives (Clemen, 1996). For example, in buying a car, minimizing cost may be an objective, and measuring cost in dollars is an appropriate attribute scale.

### *b. Objective Requirements*

Clemen (1996) states that several conditions must exist for objectives and attributes to be effective tools in decision-making:

- The set of objectives (as represented by fundamental objective hierarchy) should be complete. All relevant aspects of a decision should be included. If the decision-maker is not satisfied with the result or is unwilling to accept the results, then the set of objectives would have to be considered incomplete.

- The number (or set) of objectives should be as small as possible. Too many objectives can make the decision much harder to address. In this case, hierarchy is significant because each objective provides a useful representation of objectives that are important to the decision-maker, and each objective is different from the available alternatives.

- The set of objectives should not be redundant meaning objectives should not be repeated in a hierarchy. If there are redundant objectives, the optimal alternative may not be chosen.

- The set of objectives should be decomposable. The decision-maker should be able to think about each objective separately without having to consider others. For example, a student finding an apartment to rent may look at attributes such as monthly rent and distance from school. The student can think about these attributes separately: regardless of rent, it would be preferable to live closer to school; or, regardless of distance, it would be preferable to have low rent. Therefore, the objectives would be decomposable into the two attributes of cost and distance, which can be considered independently. If the attributes are related in a way that does not permit decomposition, then the set of objectives has to be changed.

- Means and fundamental objectives should be distinguishable. As defined above, means objectives accomplish fundamental objectives through attributes. If fundamental objectives are not well defined, there is no clear reason why a decision must take place.

- Attribute scales must be operational. These scales must provide an easy way to measure performance of each alternative or the outcomes of the fundamental objectives. The attribute scale of cost in dollars for buying an economical vehicle is a good example of this rule.

### *c. Conflicting Objectives*

When two or more objectives conflict, the challenge of recognizing the differences between each objective, and choosing the method that comes closest to solving the problem is difficult. Through implementing trade-off analysis, a decision-maker can add subjectivity by deciding how best to trade-off a more important (or dominant) objective for a lesser one.

When only two objectives conflict, the trade-off analysis is not difficult. Each alternative could be listed or ranked according to how well it meets each objective. By plotting on a standard X-Y graph, the decision-maker can move systematically in one direction, through the alternatives, switching one alternative with the next. The benefit to this method is that once a switch is made, the preferred alternative must be better, and there is no need to go back and compare to a lesser-preferred alternative.

## 2. ADDITIVE UTILITY FUNCTION

An additive utility model is a way of evaluating conflicting objectives by calculating an overall utility score. The overall utility is the "weighted sum of individual utility functions for each fundamental objective." (Clemen, 1996, p. 561) For the purposes of this research, the additive utility model can be used to choose the best remediation technology. The Additive Utility Model produces an ordinal ranking of the alternatives. Assume that there are individual utility functions $U_1(x_1),.....,U_m(x_m)$ for m different attributes $x_1$ through $x_m$, and that each function assigns a weight of 0 to the least important and 1 to the most important attribute for that particular objective. The additive utility function is defined as a weighted average of these utility functions. (Clemen, 1996) Therefore, for m different attributes ($x_1$ through $x_m$), the utility of this outcome is

$$U(x_1,\ldots,x_m) = k_1U_1(x_1) + \ldots + k_mU_m(x_m)\text{ , or}$$

$$= \sum_{i=1}^{m} k_iU_i(x_i)$$

where the weights $(k_1,\ldots,k_m)$ are positive and add up to 1.

### *a. Utility Curves*

Utility curves provide a graphical representation of the utility score in response to a change in attribute measurement. Figure A-1 depicts three types of utility function curves that represent a translation of an attribute into utility units. The curves are dependent upon expert evaluators, who through subjective input, determine factors such as the attributes to be used, the range of scores for each attribute, and the conversion factor for a score to change into a utility score. The downward curve in figure A-1(1) represents a decreasing utility function for an attribute, meaning, as the attribute increases towards the higher level of its defined range, the utility score of that attribute has decreased. For example, in the sediment treatment project, the sooner the project is completed, the better the satisfaction level of the objective. Therefore, time is the defined attribute, and the experts of the project have defined minimum and maximum total project time for each remediation technology to complete the task. If the project is completed in minimal time, the utility assessed is high (closer to 1); however, if the project takes too much time and is measured towards the upper range level, a low utility is assessed, making that particular sediment technology less desirable considering the time attribute only.

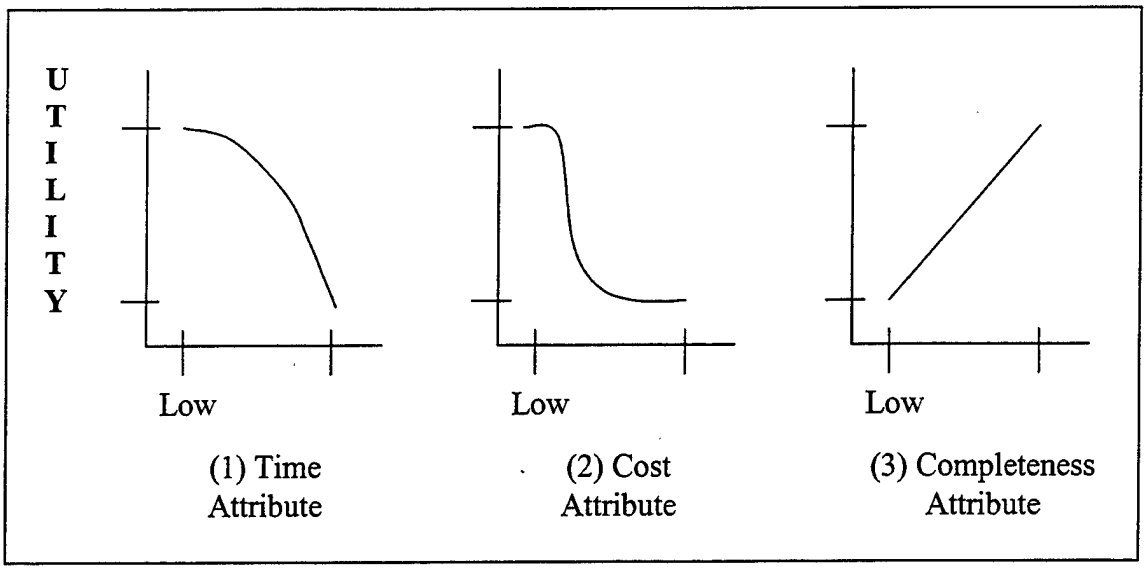


Figure A-1. Examples of Utility Function Curves.

The second curve (Figure A-1(2)), represents a higher-scoring utility for a low measure of the attribute. However, as the level of the attribute increases, the utility score decreases sharply until a certain level, and after a point the utility score is constant. For example, if the decision-makers want to complete the sediment project at a low cost, a higher utility will be given to those alternatives whose cost falls within the lower range. The third curve (Figure A-1(3)), depicts a linear curve, displays a direct relationship between an increasing attribute level and an increasing utility score. An example of this situation would be the desired level of completeness (progression of cleanup) for the sediment project, where the attribute moves towards a utility score of one, as the project becomes more complete.

### *b. Indifference Curves*

Indifference curves graphically demonstrate the set of alternatives among which a decision-maker is indifferent. In sketching indifference curves, the

decision-maker will find that each slope produced from the alternatives is related to the trade-off rate that was assessed. For example, a decision-maker may be indifferent between two sediment treatment technologies, when considering the attributes of cost and time. The total utility is the same for both alternatives, therefore, the decision-maker is indifferent between choosing the two alternatives with respect to cost and time only. The slope could also be defined as the marginal rate of substitution, or the rate at which one attribute can be used to replace another (Clemen, 1996) (see Figure A-2).

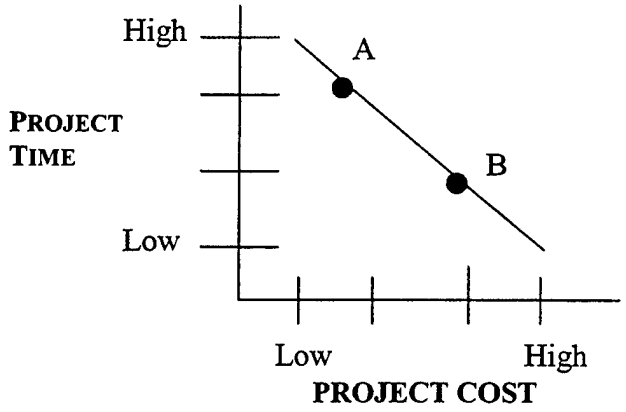


Figure A-2. Indifference Curve.

## 3. ASSESSING INDIVIDUAL UTILITY FUNCTIONS

There are different methods regarding the assessment of the individual utility functions including the assessment of ratios, the calculation of proportional scores, and the standard utility function assessment. In this appendix, the simpler methods (ratios and proportional scoring) are explained to offer a choice among determining utilities (or utility scores). For additional information, refer to Clemen (1996).

### *a. Ratios*

Ratios present a way of determining utilities based on a numerical comparison of attributes, whether the attributes are quantitative or qualitative. This method converts performance scores into utility scores, where the range of the utility scores are from zero (lowest level utility) to one (highest level utility) (see Figure A-1). Clemen (1996) uses the following example: the decision-maker decides that color is an important attribute in purchasing an automobile. Using the ratio approach for qualitative measures, the decision-maker determines a level of importance in comparing one attribute to another. In this example, the decision-maker decides that blue is twice as good as red, and that yellow is 2 ½ times as good as red. Points ranging from 0 to 100 can be given to each alternative based on its performance on the attribute. In the example, if 30 points were assigned to red, then 60 and 75 points would be assigned to blue and yellow respectively. These results can be calculated to reflect the conversion of the highest and lowest performance scores to the utility scores of 1 and 0 respectfully. First, constraints a and b need to be determined so that:

$$0 = a + b(30)$$
$$1 = a + b(75)$$

Solving these two equations simultaneously gives

$$a = -2/3$$
$$b = 1/45$$

Applying these scaling constants, the utility values for the car color are:

$$U_s \text{ (red car)} = -2/3 + (1/45)(30) = 0$$
$$U_s \text{ (blue car)} = -2/3 + (1/45)(60) = 2/3$$
$$U_s \text{ (yellow car)} = -2/3 + (1/45)(75) = 1$$

The utility of the car color could be used in conjunction with trade-offs determined for attributes such as price and fuel economy.

### *b. Proportional Scores*

Proportional scoring is another method that can be used to assess utility scores. This method assumes natural numerical measures exist (i.e. dollars and years). The lowest and highest performance measures on the attribute are assigned utility scores of 0 and 1 respectively. The calculation in this method determines the utility scores for any intermediate performance measure that exists between the lowest and highest performance measures.

The general formula is used:

$$U_i(x) = \frac{x - \text{Lowest Performance Score}}{\text{Highest Performance Score} - \text{Lowest Performance Score}}$$

$$= \frac{x - x_i^-}{x_i^+ - x_i^-}$$

Both the ratio and proportional scoring methods provide a way to calculate the utility scores for performance measures. However, another need in the additive utility function is to determine the weights of each attribute. Some of the available methods for assessing weights are explained in the next section.

## 4. ASSESSING WEIGHTS

Weighing the attributes is necessary to execute the Additive Utility Function. Weights reflect the importance of each attribute relative to the other attributes. There are various methods to assess weights including equal weighting, weights from ranks, ratio weighting, the pricing-out method and swing weighting. The simpler methods (equal weighting and weights from ranks) are explained in this appendix. In this research, the

"Smarter" method in Logical Decisions for Windows™ (1997) software is used to calculate weights in a simple manner. This computer-based application allows the user to calculate weights more expediently than by hand, and providing a user-friendly platform that automatically provides an overall assessment of evaluation to the decision-maker. For further information on the other available methods, refer to the writings of Clemen (1996) and Edwards and Newman (1982).

### *a. Equal Weighting*

Equal weighting is the easiest method to weight the attributes. The decision-maker simply assigns equal weights to each attribute. Thus, every attribute has the same weight. Equal weighting is sometimes useful when the decision-maker does not have meaningful weights obtained from the stakeholders or does not have weights at all. (Edwards and Newman, 1982) In this thesis research, the level of importance of each attribute is not the same, and considered important in selecting the optimal sediment remediation technology.

### *b. Weights From Ranks*

In this method, the decision-maker has to have an ordinal ranking of attributes (listing the most important attribute first, the second most important attribute second, and so on). A numerical weight is then assigned to each attribute according to its importance. These methods provide a simple way of assessing weights; therefore, the decision-makers can utilize these methods to legitimate their decision better to the stakeholders. There are two methods of doing assessing weights from ordinal ranking:

- *Rank Sum Weighting*: Assign the largest number to the most important attribute, the second largest number to the second important attribute, and

so on, until the list important attributes receives the rank of one. Then dividing each numerical number by the sum of all number gives weights.

- *Rank Reciprocal Weighting*: Assign the numerical value of one to the most important attribute, two to the next most important attribute, and so on. The reciprocal of each numerical number is normalized. The normalized numbers are used as the weights. (Edwards and Newman, 1982)

## C. CONCLUSION

The objective of using multiattribute decision-analysis techniques is to construct a model that is reasonable representation of a decision-maker's value structure. The Additive Utility Function provides a weighted sum of individual utility functions for each fundamental objective. There are various methods available to calculate individual utility scores and weights where the decision-maker may choose the method of preference. As a result, the additive utility model enables the decision-maker to select an alternative from a set of feasible alternatives.

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# APPENDIX B. ROLES FOR PROXY-RESTORATION ADVISORY BOARD (RAB) MEMBERS

The following is an example of the roles assigned to each proxy-Restoration Advisory Board (RAB) member. There are a total of seven roles assigned, with one participant assigned to each role.

***In your role, you are a concerned public citizen (member of the RAB – Restoration Advisory Board). Think about issues or concerns you may have regarding this site restoration. Your input will be used to choose the proper technology to remediate the polluted sites in the San Francisco Bay area.***

**CONCORD NAVAL WEAPONS STATION (NWS)**

**Background**

1. **Demographics**- Concord Naval Weapons Station (NWS) is about 35 miles northwest of San Francisco. It is surrounded by the city of Concord to the west and south (population 116,000); the city of Bay Point to the east (population 17,000); and the small town of Clyde (population 600) to the north. The size of NWS is 13,023 acres. It is the major Naval munitions facility on the west and, as an ocean terminal facility, is used to transfer ordinance from trucks and rail cars to ships and vice versa.
2. **Contaminants** – Concord NWS is contaminated with heavy metals, Petroleum, Oil, and Lubricants (POLs), volatile and semi-volatile organic compounds.
3. **Environmental Risk** –
   a. Hydrogeology – Concord NWS is bound on the north by Suisun Bay and on the south and west by the city of Concord. Surface water and sediment is the pathway of greatest concern due to the interconnection of the Tidal and Litigation areas. Groundwater at Concord NWS is not used for drinking water due to its high Total Dissolved Solids content.
   b. Natural Resources – Suisun Bay is a transition zone between saltwater and freshwater ecosystems and is interconnected to the Concord NWS wetland areas. This area contains a diverse population of fish and other aquatic wildlife. The Bay is also used for recreation. The upland and the wetland

federal and state designated threatened and endangered specious. These include the Salt Marsh Harsh Mouse, California Clapper Rail, California Black Rail, Tule Elk, and the figwort family of plants including the Delta Tule Pea, and Soft Bird's Peak.

c. Risk – Four sites are ranked as high relative risk in the DOD Relative Risk Site Evaluation System at Concord NWS primarily because of the threatened and endangered species in the sensitive wetland areas and recreational users in adjoining Suisun Bay. The close proximity of NWS to the Contra Costa County Water Wells surrounding Mallard reservoir has also contributed to the high relative risk ranking. Risk to human health and the environment have been reduced due to the remedial action for the Litigation Area Sites.

**Public Involvement**

1. **Restoration Advisory Boards (RABs)** – There are 10 active RAB members. The Navy and the regulatory agencies have given technical presentations during the monthly RAB meetings.
2. **Relevant Issues** – An Information Repository was established at the Central at the Central Contra Costa Public Library.

After reviewing this page, please go to the Delphi Website at http://www.delphi.com/nps_survey. There you will read the background information on the San Francisco Bay Sediment project, and asked to go to the *Methodology Information* and *Instructions* links.

* Information taken from DON Environmental Restoration for FY 1998-2002.

# APPENDIX C. ARTICULATED RESPONSES FROM PROXY-RESTORATION ADVISORY BOARD (RAB) MEMBERS

The following responses are the results of the discussion phase of the Delphi method. The seven-day discussion phase resulted in five responses by proxy-RAB panelists. The results were then interpreted into measurable attributes relating to the San Francisco Bay Sediment Project, and placed in a value tree (see Figure 3.3 of the Implementation and Results Chapter).

| From: **MERSIN1** |
| --- |
| To: **ALL** |
| 6.1 |
| |
| As a citizen of this area I am concerned with three major factors HUMAN, ENVIRONMENTAL and COST.<br>HUMAN ISSUES:<br>-What provisions will be taken to insure "Public Safety"?<br>The Government will cover –What health issues? (Birth defects, Cancer, Respiratory, Digestive)<br>-Will public notices be given? (Newspaper, Radio, TV)<br>-Will the local community be allowed to take part in the planning of the restoration?<br>-What effects will the area have on our pets?<br>-What is the level of contaminants in the water supply?<br>ENVIRONMENTAL:<br>-How long will the clean up take?<br>-What is the schedule? (Start, Completion)<br>-How many phases are planed for the clean up and what are they?<br>-Will the public be given a map of the contaminant area?<br>-What environmental studies have been conducted and will they be shared with the public?<br>-What is the acceptable levels of contaminants in the air, soil and water? Do they meet EPA standers?<br>-How long will it take for the earth too naturally restore the area?<br>-What harmful gases will be in the air and soil?<br>-What is the short and long-term uses for the area?<br>-What effects has the contaminants had on the stability of the soil to support the foundation of future building in the area? |

COST:
-What will it cost to conduct the clean up?
-Who will absorb the cost?
-Will this lead to a deprecation of the local area?

| |
|---|
| From: **FETHIYE1** |
| To: **MEMOCAN** unread |
| 5.3 in reply to 5.1 |
| |
| What will the facility be used for in the future? - This is of primary importance, because it will determine the amount of clean-up that is required.<br>Can we transfer the land prior to clean-up? - This allows the Navy to stop paying for operating costs (security, fire, etc.) during the clean-up effort. However, private landowners are very concerned with their liability upon transfer.<br>What remediation technology is proposed to prevent contamination of the bay? - This is the biggest environmental risk, yet because it is a long way off (slow flow of pollutants to the bay), and it doesn't directly impact development, it may be a low priority to the public. However, the Navy needs to plan for the remediation effort--whether it be in situ or via extraction (e.g., bioslurper technology). |

| |
|---|
| From: **PWHITE27** |
| To: **MEMOCAN** |
| 5.2 in reply to 5.1 |
| |
| Where will the sediment go once it is treated?<br>Realizing pollution of San Francisco Bay is possible what percentage chance would you assign that collateral pollution may be caused by the cleanup effort? Collateral meaning airborne and waterborne pollutants contaminating the bay/air in the surrounding area as the cleanup progresses.<br>What measures will be taken to ensure the safety and health of the surrounding population?<br>What impact will the cleanup have on the surrounding wildlife and fisheries?<br>How long will the cleanup take?<br><br>Edited 11/24/99 6:13:32 PM ET by PWHITE27 |

| From: **VAN110** | 3:26 pm |
|---|---|
| To: **ALL** | (1 of 1) |
| 8.1 | |

I am a concerned public citizen and member of the RAB – Restoration Advisory Board. I have three major concerns:
1) How can I be assured that the Navy is accurately informing the public of the hazardous materials stored (past and present) at Concord NWS.
2) If the groundwater at Concord NWS is not suitable for human consumption, how can I be assured that water fowl are not at risk of chemical exposure. What measures have been taken to ensure that water fowl safety?
3) Likewise, are local residents that use Suisun Bay for recreational boating and fishing safe. Is it safe to consume fish and wildlife from Suisun Bay (but not safe to drink the water)?

| From: **SERENEDAY** | 1:19 am |
|---|---|
| To: **ALL** | (1 of 1) |
| 7.1 | |

As a member of RAB, there are 3 main concerns:
1. Short/long term effects of exposure to both known and unknown contaminates to people.
2. Safety of wildlife.
3. Migration of the contaminated water to populated areas.

Points:

Concerns 1 and 3: This site is a known place for migratory fish, shellfish, birds, and mammals, including, crab and shrimp. Fish from this area can, and probably will migrate to populated fishing areas. There has been no study to show the effects of human consumption of such contaminated foods. Additionally, although identified as a potential issue, there have been no studies to delineate exposure of on-site personnel through direct contact with both the soil and the near surface ground water, which is likely connected to the San Francisco Bay. In turn, this presents the further issues of migrating contaminates. Lastly, the soil supporting the Island (TI) is man-made composed of dredged materials consisting of poorly graded "fine" sand placed over Yerba Buena Shoals. This will allow for the contaminates to seap through to the water. Additionally, although YBI is a natural rock island with minimal soil cover, there is still the issue of runoff contaminates into the water. It is foreseeable that the contaminates from both of these areas would transport potential contaminants to the Bay or runoff would infiltrate into the Franciscan sandstone and shale.

Concern 2: It is known that this area hosts migratory birds, mammals, and fish. These include waterfowl and passerine birds, the California sea lion and harbor seal. A survey of both Federal and California endangered or threatened species identified seven animals and 17 plant species in the contaminated area.

Overall: There have been no studies showing what the effects of how the removal from one site will effect the water and soil. Where will it be removed to? stored? Process? effect on wildlife? Due to the ongoing possible contamination of the water, it would be more amenable to the community to have the entire site cleaned. This would cause less disruption to the wildlife and it would ensure as little further contamination of the water as possible.

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